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(C) TRANSVERSE MOTION OF 8 INCH PROJECTILE, XM673, IN THE XM201, M2A2 GUN TUBE, MK-16 AND MCLG GUN (U)

> BY S. H. CHU

AUGUST 1973

AMCMS CODE: 6646.03.12263

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ABSTRACT

The dynamic behavior of a projectile during acceleration in the gun tube requires a quantitative discription, since if balloting becomes excessive, undesirable conditions such as damage to fuzing. shell body engraving, inaccuracy of fire due to yaw, and yaw velocity at the muzzle may result. The approach taken in this report utilize the equations of motion derived in an earlier report titled, "Transverse Motion of an Accelerating Shell" [1] to describe the balloting motion of the 8-inch XM673 projectile fired in the MK-16, MCLG gun, XM201 and M2A2 gun tubes.

Most previous solutions which have appeared in published works to date discuss the problem in a simple way, or consider separately the main factors that effect projectile motion. Effects of friction forces at the bourrelet and the driving band, changes of the eccentricity and the location of the center of gravity, and the wall thickness of the shell were considered in this formulation.

The analysis shows that the contact of the bourrelet on the gun tube is intermittent when the C. G. eccentricity is zero or very small and the contact is continuous when the eccentricity is large and that this parameter is the one that most effects the performance of the projectile and the associated fuze. The analytical results are presented in graphic form.

INTRODUCTION

As part of the design and evaluation of the 8 inch XM673 projectile, an analysis was performed of the balloting motion of the projectile if fired from each of the MK-16 and MCLG guns and the M2A2 and XM201 gun tubes. Since the projectiles are precisely machined it is assumed that the projectile configuration is symmetrical about its geometrical axis, which is taken as the 3'-axis of the moving body coordinate system 1', 2', 3' (Fig. 1). The mass distribution of the projectile was considered to have various degrees of non-uniformity. For zero eccentricity, the center of gravity of the projectile will be at the 3'-axis, otherwise it has an eccentricity of some magnitude from the 3'-axis. As in Reference 1, another moving body coordinate system 1, 2, 3 was selected and made parallel to the 1', 2', 3' system with its origin at the center of gravity of the projectile. Since the eccentricity of the center of gravity is usually small, it is assumed that the products of inertia of the projectile about the coordinate system 1, 2, 3 may be ignored and that the projectile has constant polar and transverse moments of inertia about this moving coordinate system.

The calculation is done with the assumption that the gun tube is rigid, stationar, and straight, and the geometrical projectile axis always intersects the center of the driving band diameter and that the latter is always centered along the gun tube axis. The 3-axis of the coordinate system 1, 2, 3 may or may not coincide with the 3'-axis of the system 1', 2', 3', but the corresponding axes are parallel to each other. The eccentricity, ϵ , is expressed in inches and is the distance between the 3- and the 3'-axis. It may also be expressed in terms of the moment (in-oz) of the projectile weight about the geometrical axis of the projectile, i. e. the product of the projectile weight (oz.) and the eccentricity distance (in.). Hence the eccentricity distance (in.) is equal to the eccentricity moment (in-oz.) divided by the projectile weight (oz.) Four cases with $\epsilon = 0$, 10, 25 and 50 in-oz respectively and a projectile wall thickness t = 0.40 in. are computed for each type of gun tube to show the effects of the eccentricity. To investigate the effects of (1) friction forces, (2) projectile wall thickness and (3) location of center of gravity

of the projectile, cases with (1) no friction forces, (2) wall thicknesses of 0.38 and 0.42 inches respectively, and (3) distance from the bourrelet to the driving band unchanged but with the distance from the center of gravity to the driving band reduced to three quarters and one half the original value respectively, are computed for the XM201 gun tube only.

In these computations the equations of motion derived in Reference 1 have been used with the additice of friction forces, both at the bourrelet and the driving band, to increase the accuracy of the computation.

THEORY

The coordinate systems and Euler's angles used in the computations are shown in Fig. 1. The Z-axis is taken along the gun tube and gun elevation is 45 degrees with the X-axis positioned horizontally and the Y-axis perpendicular. Consequently, the angle α used in the following equations of motion is taken as 135 degrees.

The equations of motion are derived in the same way as shown in Reference 1 with the exception that the friction forces and their associate moments are added to the original forces and moments at the bourrelet and the driving band. For easy understanding of the computations and completness of this report, some of these equations and the related definitions of symbols are repeated below.

The six equations of motion are:

$$m \underbrace{\begin{cases} \vdots \\ \theta \\ \cos \theta \\ \sin \psi + \psi \\ \sin \theta \\ \cos \psi - (\psi + \theta) \end{cases}}_{-\psi} \underbrace{\begin{cases} \vdots \\ \theta \\ \sin \theta \\ \cos \psi \\ \cos \theta \\ \cos \psi \\ \cos \psi \\ \cos \theta \\ \cos \psi \\ \cos \psi \\ \cos \theta \\ \cos \psi \\$$

$$-2\dot{\phi}\dot{\theta}\cos\phi\sin\theta\sin\psi-2\dot{\psi}\dot{\theta}\sin\phi\sin\theta\cos\psi$$

$$= (F_{bl} + F_{cl}) \cos \psi - (F_{b2} + F_{c2}) \cos \theta \sin \psi + (F_{b3} + F_{c3}) + Apsec \theta \sin \theta \sin \psi$$
(1)

$$m \Re \left[\psi \sin \theta \sin \psi - \theta \cos \theta \cos \psi + (\psi + \theta) \sin \theta \cos \psi + 2 \psi \cos \theta \sin \psi \right]$$

$$+ \, m \in \stackrel{\bullet}{[\phi]} (\cos \phi \cos \theta \cos \psi - \sin \phi \sin \psi) + \stackrel{\bullet}{\psi} (\cos \phi \cos \psi - \sin \phi \cos \xi \sin \psi)$$

.. .2 .2 -
$$\theta \sin \phi \sin \theta \cos \psi - (\psi + \phi)(\cos \phi \sin \psi + \sin \phi \cos \theta \cos \psi)$$

.2 -
$$\theta \sin \phi \cos \theta \cos \psi - 2\phi \theta \cos \phi \sin \theta \cos \psi + 2\psi \theta \sin \phi \sin \theta \sin \psi$$

$$-2 \overset{\cdot}{\phi} \psi \; (\cos \phi \cos \theta \sin \psi + \sin \phi \cos \psi)]$$

$$= (F_{bl} + F_{cl}) \sin_{\psi} + (F_{b2} + F_{c2}) \cos\theta \cos_{\psi} - (F_{b3} + F_{c3} + Apsec_{\theta}) \sin\theta \cos_{\psi} + mg\cos_{\alpha}$$

$$(2)$$

$$\begin{array}{c} \vdots \\ \text{mW-m} \ \mathcal{Q}(\theta \sin \theta + \theta \cos \theta) + \text{m} \in [\phi \cos \phi \sin \theta + \theta \sin \phi \cos \theta + \theta \sin \phi \cos \theta] \end{array}$$

$$\begin{array}{c} \vdots \\ -(\phi + \theta) \sin \phi \sin \theta + 2\phi \theta \cos \phi \cos \theta \end{array}]$$

=
$$(F_{b2}^{+}F_{c2}) \sin\theta + (F_{b3}^{+}F_{c3}^{+}Apsec\theta)\cos\theta - mg\sin\alpha$$
 (3)

$$I(\theta_{-\psi}^{\circ} \sin\theta \cos\theta) + I_{3\psi}^{\circ} (\psi \cos\theta + \phi) \sin\theta$$

$$= M_{bl} + M_{cl} - Ap \in \sin \phi \sec \theta \tag{4}$$

$$I(\psi \sin\theta + 2\psi \theta \cos\theta) - I_3 \theta (\psi \cos\theta + \phi)$$

$$= M_{b2} + M_{c2} + Ap \in \cos \phi \sec \theta \tag{5}$$

$$I_{3} (\psi \cos \theta + \phi - \psi \theta \sin \theta)$$

$$= M_{b3} + M_{c3}$$
(6)

where

 ψ , θ , ϕ = Euler's angles (radians), ψ , $\dot{\theta}$, $\dot{\phi}$ and ψ , θ , $\dot{\phi}$ are the corresponding velocities (rad/sec) and accelerations (rad/sec²) respectively

 \mathcal{Q} = distance from C.G. to driving band (in)

∈ = eccentricity of C.G. from geometrical projectile axis (in.)

 $A = area of bore (in.^2)$

 α = Y-axis inclination to the horizontal line (radians)

W= axial displacement of driving band diameter center (in.). W and W are the corresponding velocity (in/sec) and acceleration (in/sec²).

g= gravitational acceleration, 386 in/sec²

m = mass of projectile (lb -in -sec)

I = transverse mass moment of inertia of projectile (lb -in -sec²)

I₃ = polar mass moment of inertia of projectile
 (lb -in -sec²)

p = firing pressure (psi)

 F_{bl} , F_{b2} , F_{b3} = total bourrelet contact force components along the 1-, 2-, and 3-axis respectively (lbs.)

F_{cl}, F_{c2}, F_{c3} = total driving band contact force components along 1-, 2-, and 3-axis respectively (lbs.)

M_{bl}, M_{b2}, M_{b3} = total moment components of bourrelet contact forces about the 1-, 2-, and 3-axis respectively (in-lb)

M_{cl}, M_{c2}, M_{c3} = total moment components of driving band forces about the 1-, 2-, and 3-axis respectively (in-lb)

The friction forces are equivalent to the products of the normal forces and the frictional coefficients. The friction coefficient for the bourrelet contact is taken as that of dry sliding of mild steel on mild steel, equal to 0.57 [2]. The friction coefficient at the driving band contact is obtained from several trial computations. First a frictional coefficient is assumed for use in calculating the travle and velocity of the projectile. The results are then compared to those from interior ballistics computations with the same firing pressure. The computation is repeated, varying the friction coefficient until a reasonable agreement is reached, and then that coefficient is taken as the desired one. The normal forces are obtained from the contact forces at the bourrelet and the driving band. The compressive pressure exerted on the driving band by the gun tube is also included. Since there are no simple equations available for this pressure calculation, an approximate pressure distribution of 40,000 and 20,000 psi based on average experimental maxin.um and mimimum data is assumed at the breech and the muzzle portion, respectively, in the computation.

With the addition of the friction forces and their associated moments at the bourrelet and the driving band contact, the total components of the forces and moments may be computed with the following equations:

The total forces and moments at the bourrelet contact are:

$$F_{bl} = \frac{-\mu_b E t^3 R\theta (\dot{\psi} + \dot{\phi} \cos\theta) [r\cos\theta + \frac{\theta}{101} (h + \dot{Q}) \sin\theta - R]}{0.135 r^2 |\theta| (\dot{W} - \frac{R\theta \dot{\theta}}{101})^2 + R^2 (\dot{\psi} + \dot{\phi} \cos\theta)^2}$$
(7)

$$F_{b2} = \frac{\text{Et}^{3}}{0.135 \text{r}} 2 \left[\text{rcos}_{\theta} + \frac{\theta}{10!} (\text{h} + \Omega) \sin \theta - R \right]$$

$$\times \left[\frac{\theta}{10!} \cos \theta - \frac{\lambda_{b} \left(\dot{W} - \frac{R\theta \dot{\theta}}{10!} \right) \sin \theta}{\left(\dot{W} - \frac{R\theta \dot{\theta}}{10!} \right)^{2} + R^{2} \left(\dot{\psi} + \dot{\phi} \cos \theta \right)^{2}} \right]$$
(8)

$$F_{b3} = -\frac{Et^{3}}{0.135r^{2}} \left[r\cos\theta + \frac{\theta}{101} \left(h + \mathcal{L}\right) \sin\theta - R\right]$$

$$\times \left[\frac{\theta}{101} \frac{\sin\theta + \frac{\mu_{b}}{101} \left(\dot{W} - \frac{R\theta\theta}{101}\right) \cos\theta}{\left(\dot{W} - \frac{R\theta\theta}{101}\right) + R \left(\psi + \phi \cos\theta\right)}\right]$$
(9)

$$M_{\text{bl}} = -\frac{\text{Et}^{3}}{0.135r^{2}} 2 \left[\text{rcos}\theta + \frac{\theta}{101} (h + \Omega) \sin \theta - R \right]$$

$$\times \left\{ \frac{h\theta \cos \theta}{101} - \left(r + \frac{\epsilon \theta}{101} \sin \phi \right) \sin \theta \right.$$

$$= \frac{u_{\text{b}} \left[h \sin \theta + \frac{\theta}{101} \left(r + \frac{\epsilon \theta}{101} \sin \phi \right) \cos \theta \right] \left(\dot{W} - \frac{R \theta \dot{\theta}}{101} \right)}{\left(\dot{W} - \frac{R \theta \dot{\theta}}{101} \right)^{2} + R^{2} \left(\dot{\psi} + \dot{\phi} \cos \theta \right)^{2}}$$

$$(10)$$

$$M_{b2} = -\frac{Et^{3}}{0.135r} 2 \left[r \cos\theta + \frac{\theta}{101} \left(h + Q \right) \sin\theta - R \right]$$

$$\times \left\{ \frac{\theta \sin\theta}{|\theta|} + \frac{\omega_{b} \left[\frac{h\theta R}{101} (\psi + \phi \cos\theta) + (W - \frac{R\theta\theta}{101}) \cos\theta \right]}{\sqrt{(W - \frac{R\theta\theta}{101})^{2} + R(\psi + \phi \cos\theta)^{2}}} \right\}$$
(11)

$$M_{b3} = -\frac{Et^{3}}{0.135r} 2 \left[r \cos\theta + \frac{\theta}{|\theta|} (h + \hat{\lambda}) \sin\theta - R \right]$$

$$\times \left\{ \frac{u_{b} \left[R(\psi + \phi \cos\theta) (r + \frac{\epsilon \theta}{|\theta|} \sin\phi) + \epsilon (W - \frac{R \theta \theta}{|\theta|}) \sin\theta \cos\phi \right]}{\sqrt{(W - \frac{R \theta \dot{\theta}}{|\theta|})^{2} + R^{2}(\psi + \phi \cos\theta)^{2}}} \right.$$

$$\left. - \frac{\epsilon \theta}{|\theta|} \cos\theta \cos\phi \right\}$$
(12)

and the components of the total forces and moments at the driving band are:

$$-2\pi \mu_{c}^{R} \operatorname{Rp}_{c} \operatorname{d} \cos_{\gamma}(\operatorname{sin}_{\theta} - \operatorname{cos}_{\theta} \sin_{\theta}) \qquad (16)$$

$$M_{c2} = 2\pi \operatorname{Rf}_{n} \left[\operatorname{R}(\cos_{\gamma} - \mu_{c} \sin_{\gamma}) \sin_{\theta} - \operatorname{cos}_{\theta} \cos_{\theta} (\sin_{\gamma} + \mu_{c} \cos_{\gamma}) \right] + \frac{\operatorname{Rf}_{sm}}{2} \left\{ \pi \left[\left(\frac{8R}{3\pi} \sin_{\theta} + \operatorname{cos}_{\theta} \right) (\cos_{\theta} - \mu_{c} \sin_{\gamma} \sin_{\theta}) \sin_{\theta} - \operatorname{Q}(\mu_{c} \sin_{\gamma} \cos_{\theta} + \sin_{\theta}) \right] - 4\mu_{c} \left[\left(\frac{\pi R}{4} \sin_{\theta} + \operatorname{cos}_{\theta} \right) \right] \right\} - 2\pi \mu_{c} \operatorname{Rp}_{c} \operatorname{d} \left(\operatorname{cos}_{\gamma} \cos_{\theta} \cos_{\theta} + \operatorname{R} \sin_{\gamma} \sin_{\theta} \right) \qquad (17)$$

$$M_{c3} = 2_{\pi}Rf_{n} \left[R \left(\cos_{\gamma} - \mu_{c} \sin_{\gamma} \right) \cos\theta + \left(\sin_{\gamma} + \mu_{c} \cos_{\gamma} \right) \cos\phi \sin\theta \right]$$

$$+ 2_{\pi}\mu_{c}Rp_{c} d \left(\left(\cos_{\gamma} \sin\theta \cos\phi - R \sin_{\gamma} \cos\theta \right) + \frac{Rf_{sm}}{2} \left\{ \pi \left[\left(\frac{8R}{3\pi} \sin\phi_{s} + \left(\cos\phi \right) (\cos\psi_{s} - \mu_{c} \sin_{\gamma} \sin\psi_{s}) \cos\theta \right) + \left(\frac{8R}{3\pi} \cos\phi_{s} - \left(\sin\phi \right) (\mu_{c} \sin_{\gamma} \cos\psi_{s} + \sin\psi_{s}) \right] \right\}$$

$$+ 4\mu_{c} \left[\left(\frac{\pi}{3} R \sin\phi_{s} + \left(\cos\phi \right) \cos_{\gamma} \sin\theta - \frac{R}{3} \sin_{\gamma} \cos\theta \right) \right\}$$

$$+ 4\mu_{c} \left[\left(\frac{\pi}{3} R \sin\phi_{s} + \left(\cos\phi \right) \cos_{\gamma} \sin\theta - \frac{R}{3} \sin_{\gamma} \cos\theta \right) \right]$$

$$+ (18)$$

where E = Young's modulus of projectile wall material, psi
r = radius of projectile, in.
t = thickness of projectile wall, in.

R = radius of bore, in.

d = width of driving band, in.

h = distance from C.G. to the bourrelet, in.

 $|\theta|$ = absolute value of θ , rad. $\frac{\theta}{\theta}$ is used to change the sign of the related quantity when θ becomes negative

 $\mu_{\rm b}$ = friction coefficient at the bourrelet

 μ_c = friction coefficient at the driving band

f = maximum side normal force at the driving band per unit of circumferential length, lb/in

p = driving band pressure, psi

v = twist angle of rifling, rad.

φ_s = angle from the diameter of the region where the side forces are acting at the driving band to the node axis or l-axis, rad.

 ψ_s = projection of ϕ_s angle on the cross-sectional plane of the gun tube, rad.

The displacement of the center of the driving band diameter is related to the other quantities by the equation

$$\dot{\mathbf{W}} \tan \mathbf{v} = \mathbf{R} \left(\dot{\mathbf{v}} + \dot{\mathbf{\sigma}} \cos \theta \right) \tag{19}$$

INPUT DATA FOR COMPUTATIONS

Computations were performed for the 8 inch, XM673 projectile fired in the XM201 and M2A2 gun tubes, and MCLG and MK-16 guns respectively. The shell has the following dimensions and

properties:

- L (distance from driving band to bourrelet) = 11.539 in.
- (distance from driving band to C.G.) = 9.266 in.
 (6.950 and 4.633 in. respectively are used to compute the effect of change of C.G. location for the XM201 gun tube)
- h (distance from bourrelet to C. G.) = L Q
- s (distance from C.G. to nose of projectile) = 26.87 in.
- t (wall thickness) = .40 in. (.38 and .42 in. respectively are used to compute the effect of wall thickness for the XM201 gun tube)
- (eccentricity of C.G. from the geometrical axis of
 projectile) = 0, 10, 25 and 50 in-oz (i.e. 0, .00313,
 .00781 and .01563 in. eccentricity distance)
- E (Young's modulus for the projectile steel) = 30×10 psi
- I (transverse weight moment of inertia) = 15745 lb-in
- I_3 (polar weight moment of inertia) = 1831 lb-in²
- mg (weight of projectile) = 200 lbs.
 - r (radius of projectile bourrelet) = 3.997 in

All the guns have a bore of 8.00 inches and are positioned at the elevation of 45 degrees so that α value used in the computation is 135 degrees or 2.356 radians. The other characteristics of the guns are:

Gun or Gun Tube Type	TL(Travel), in.	y(Twist Angle), deg.
XM201	274.0	8.92705
M2A2	168.0	7.16246
MK-16	388.7	7.16246
MCLG	394.4	8.92705

The initial conditions of the shell for all computations are taken as:

$$\psi = 0,$$
 $\dot{\psi} = 0,$ $X = 0,$ $\dot{X} = 0,$
 $\theta = .0001 \text{ rad.}, \dot{\theta} = 0,$ $Y = 0,$ $\dot{Y} = 0,$
 $\phi = 0,$ $\dot{Z} = 0,$ $\dot{Z} = 0,$

The coefficient of friction μ_b at the bourrelet was taken as .57 and that at the driving band, μ , was determined by the method described earlier to be .004, .009, .02 and .02 for XM201, M2A2 gun tubes, MK-16 and MCLG guns, respectively.

The firing pressure for the various guns or gun tubes used in the computations are the given base pressures as shown in Figs. 2a, 2b, 24, 31 and 38, respectively. The same firing pressure is used for all computations for the respective gun or gun tube.

RESULTS OF COMPUTATIONS AND DISCUSSION

The results of computations are presented by the following figures:

Figs. 2a, 2b, 24, 31 and 38 show the base firing pressure and the travel of the shell inside the gun tube with respect to time (milliseconds) for the XM201, M2A2 gun tube, MCLG and MK-16 gun respectively. The base firing pressure was given and the travel was computed. The same given firing pressure is used for computations of all cases of the same type of gun tube

or gun. The travel variations of different cases of the same type of gun tube or gun are very small. Consequently, the pressure and the travel curves of various cases for each type of gun tube or gun are presented by one curve respectively.

Figs. 3a, 3b, 25, 32 and 39 show the computed velocity and the acceleration at the center of gravity of the projectile with respect to the time for the XM201, M2A2 gun tube, MCLG and MK-16 gun respectively. The variations in velocity and acceleration become noticeable only near the end of firing when the firing pressure is decreasing rapidly. But they are still of very small magnitude. Consequently, the corresponding travel variations are also very small as mentioned before.

Figs. 4-7, 26, 33 and 40 present the paths or the polar positions of the C.G. and the bourrelet center as seen from the muzzle down to the breech, for the various cases of the XM201, M2A2 tube, MCLG and MK-16 gun. The R value denotes the scale of the drawing and it is the radius of the circle in inches. It is seen that when there is no or small C.G. eccentricity the shell will make intermittent contact with the gun tube, but contact is continuous as the eccentricity increases. The friction forces will retard the rotation of the shell with respect to the gun tube. The polar distance of both the C.G. and the bourrelet center decrease with thicker walled shell and shorter distance between the C.G. and the driving band. The precession angle is retarded by friction and low values of eccentricity.

Figs. 8-11, 27, 34 and 41 show the results of computations of the angular positions (in degrees) of the contact points on the gun tube and the bourrelet of the projectile respectively with respect to the projectile travel (inches), for the XM201, M2A2 gun tube, MCLG and MK-16 gun. The deflection at the bourrelet, normal to the gun tube wall, is also plotted. It is again seen that the contact of bourrelet on the gun tube is intermittent when the C.G. eccentricity is zero or very smal, and the contact is continuous when the eccentricity is large. The path of the contact point on the bourrelet is not always a horizontal straight line when plotted against projectile travel, which indicates that the motion of the projectile may not be considered as that of a compound pendulum with its oscillation plane rotating about the

gun tube axis. The frictional forces seem to cause the precession angle to be smaller than for the no friction cases, however, the presence of eccentricity is a more significant factor. The deflection at the bourrelet increases with larger magnitude of the eccentricity, thinner projectile wall and longer distance between the C.G. and the driving band, respectively.

Figs. 12-15, 28, 35, and 42 present the computed results of the angles, velocities and accelerations of yaw for different cases of the XM201, M2A2 gun tube, MCLG and MK-16 gun. The effect of increasing the C.G. eccentricity or the projectile wall thickness, and decreasing the friction or the C.G. to driving band distance, respectively seem to increase the variation frequency in the yaw angle, velocity and acceleration of the projectile.

Figs. 16-19, 29, 36, and 43 show the results of computations of accelerations normal to the projectile axis and at the C.G., the bourrelet center, and the axial points with a distance from the projectile nose equal to 2.5, 5.0, 7.5, and 15.0 inches, respectively, for the XM201, M2A2 gun tube, MCLG and MK-16 gun. They indicate that the normal accelerations will increase when the C.G. eccentricity is increased or when there is no friction. The variation frequency of the normal acceleration seems to increase with projectile wall thickness or shorter C.G. to driving band distances.

Figs. 20-23, 30, 37 and 44 show the forces acting on the projectile at the contact point of the bourrelet with the gun tube against the time (ms), for the XM201, M2A2 gun tube, MCLG and MK-16 gun, respectively. The force component F_1 is in the direction of the yaw or nutation axis, F_2 is perpendicular to both the yaw and the shell axis, and F_3 is along the shell axis. Their magnitudes are presented in terms of mg's or in weights of the shell. It is seen that the forces will increase with greater C.G. eccentricity, shell wall thickness and distance between the C.G. and the driving band. The force component F_1 is zero and F_3 nearly zero when there is no friction.

A summary of some results is presented in Table I.

CONCLUSION AND RECOMMENDATIONS

Based on the calculated data and as indicated in the discussion, it is concluded that the eccentricity of the center of gravity of the projectile from its geometrical axis has the greatest effect on the motion of the shell inside the gun tube. The motion of the shell becomes more complicated when the eccentricity is increased. The motion may not be considered as that of a compound pendulum with its oscillation plane rotating about the gun tube axis. When eccentricity is very high, this condition tends to be approached. The deflection at the bourrelet, the yaw angle, the normal acceleration of axial points and the bourrelet contact force are increased with larger C.G. eccentricity.

Since the increase of the C.G. eccentricity increases rapidly the bourrelet contact force and the normal accelerations at the axial points of the shell and these quantities may affect the performance of the shell and the associated fuze, it is therefore recommended that the C.G. eccentricity be made as small as possible so as to improve the shell performance.

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- 2. Baumeister, Theodore and Marks, Lionel S. (Editors): Standard Handbook for Mechanical Engineers, Seventh Edition, page 3-35, McGraw-Hill Book Company, 1967.

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TABLE I SUMMARY OF RESULTS	PEAK LATERAL FORCE AT BOURRELET, mg's	10 48 112 196	8 54 110 214	102 114	85 83
	PEAK NORWAL ACC. AT FUZE (2.5 in. FRCM SHELL NOSE) g's	14 103 228 393	15 136 264 503	218 222	211 255
	Angle, Velogity 10 rad. rad/sec (Abs.	33 153 498 471	66 130 566 971	261 405	96 96
	YAW AT Angle, 10 rad.	63 1197 2318 3853	170 1147 2386 4405	2582 1684	, 1679 1882
	PEAK AXIAI ACC., g's	8500 8500 8496 8488	8548 8548 8548 8548	8648 4648	8648 8648
	VELOCITY AT MUZZLE fps	2507 2504 2496 2486	2530 2530 2530 2530	96ħZ 26ħZ	2499 2501
	C.G. ECCENTRICITY, in-oz.	0 10 25 50	0 10 25 50	25 25	25
	SHELL WALL THICKNESS, in.	04. 04.	04. 04. 04.	.38	e 04.
	GUN OR S' GUN TUBE TYPE	XMZOI	XM201 No Friction	XM2O1	XM201 Original C.G. to Driving Band Distance Reduced By: 3/4 1/2

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(ontinued)	PEAK IATERAL FORCE AT BOURRELET, mg's	26 38 57	9 138 254 254	8 55 101 172		
	PEAK NOFWAL ACC. AT FUZE (2.5 in. FROM SHELL NOSE) g's	12 4,6 1,8 87	13 103 293 565	11 108 191 317		
	Angle, Velogity 10-6 10-3 rad. rad/sec (Abs.	73 58 181 71	33 120 1292 1189	66 571 7 802		
ULTS (C	YAW AT Angle, 10-6, rad.	264 761 899 1203	111 1052 2297 4199	343 1064 1762 3448		
TABLE I SUMMARY OF RESULTS (Continued)	PEAK AXIAL ACC., g's	8300 8300 8296 8290	8222 8222 8218 8206	681C 6802 6778 67,92		
	VELOCITY AT MUZZLE fps	1879 1877 1875 1872	3050 3045 3032 3015	2811 2805 2798 2787		
TABLE	C.G. ECCENTRICITY in-oz.	0 10 25 50	0 10 25 50	0 10 25 50		
	SHELL WALL THICKNESS, in.	04. 04. 04.	0†. 0†. 0†.	04. 04.		
	GUN OR. GUN TUBE TYPE	MZAZ	MCLG	мк-16		

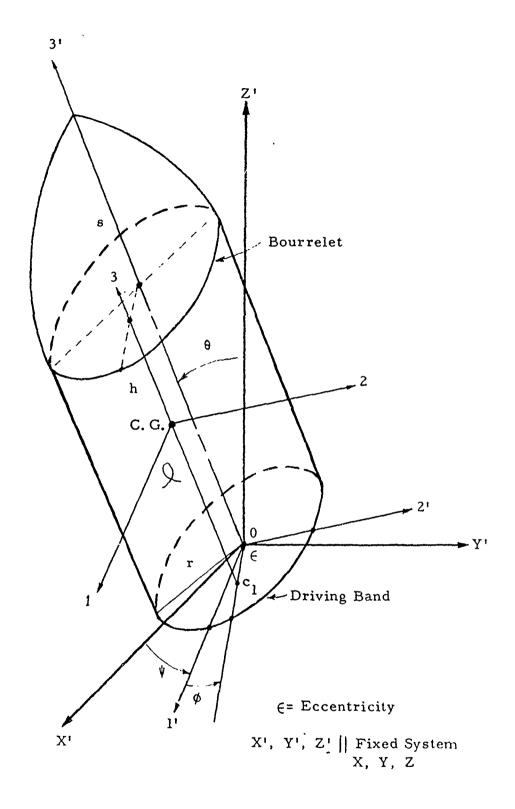
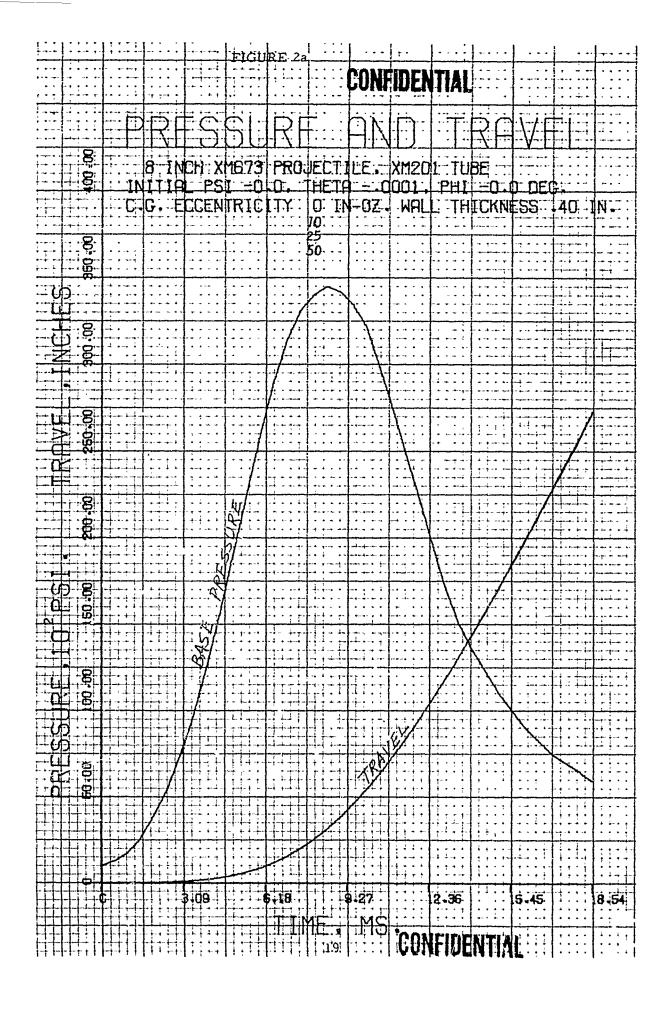


FIGURE 1

Coordinate Systems and Euler's Angles
18

XM201 TUBE



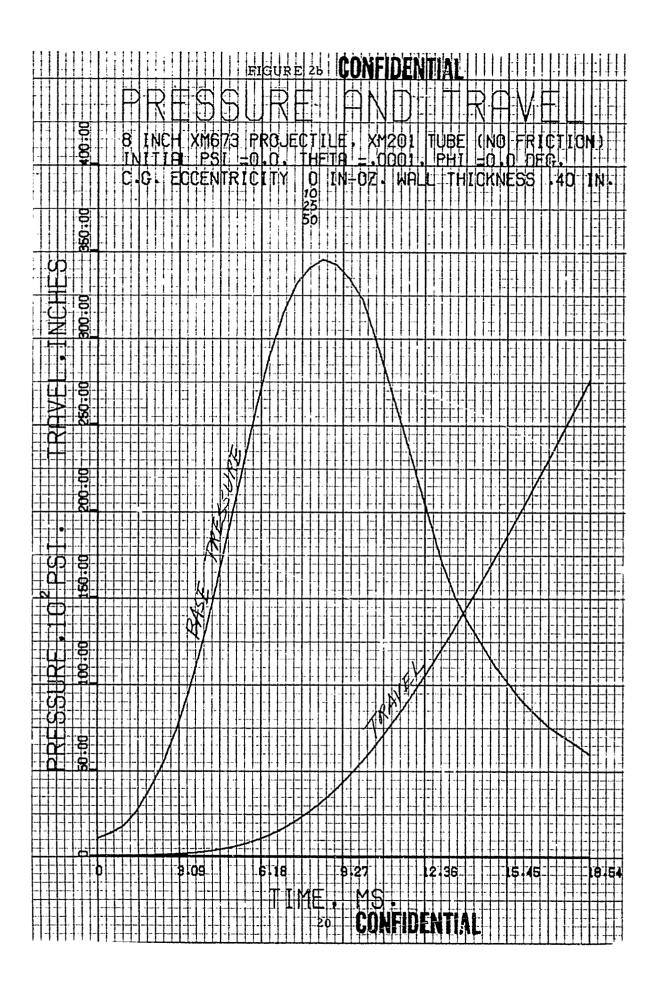
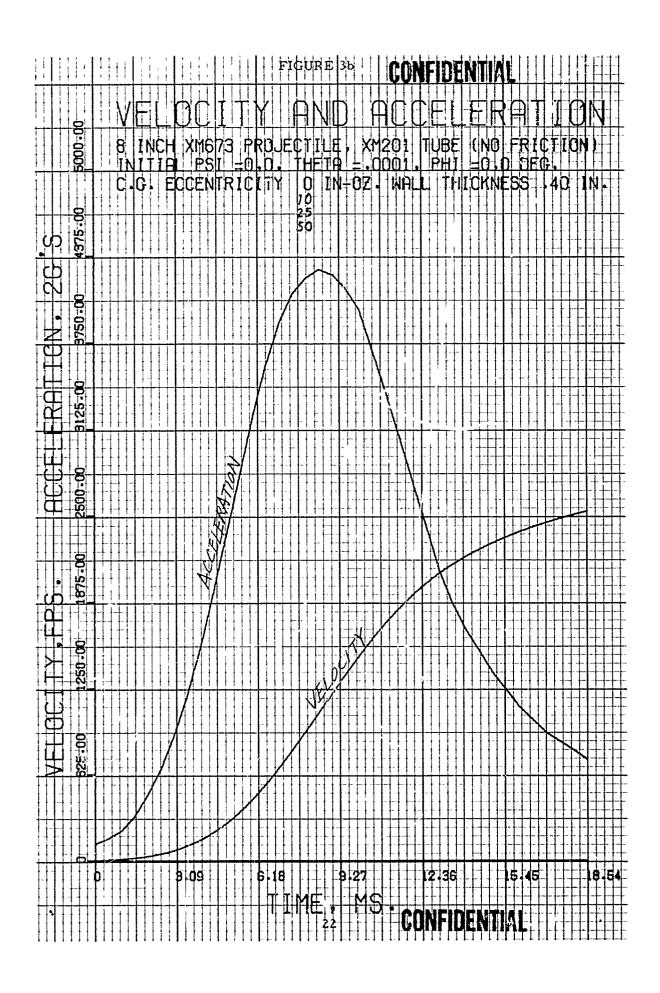
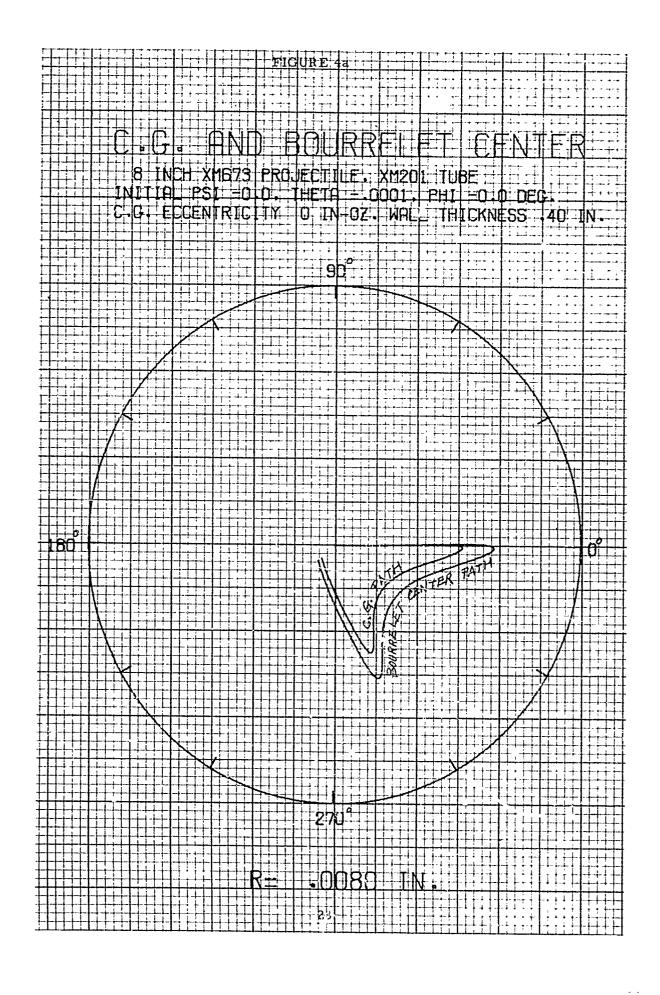
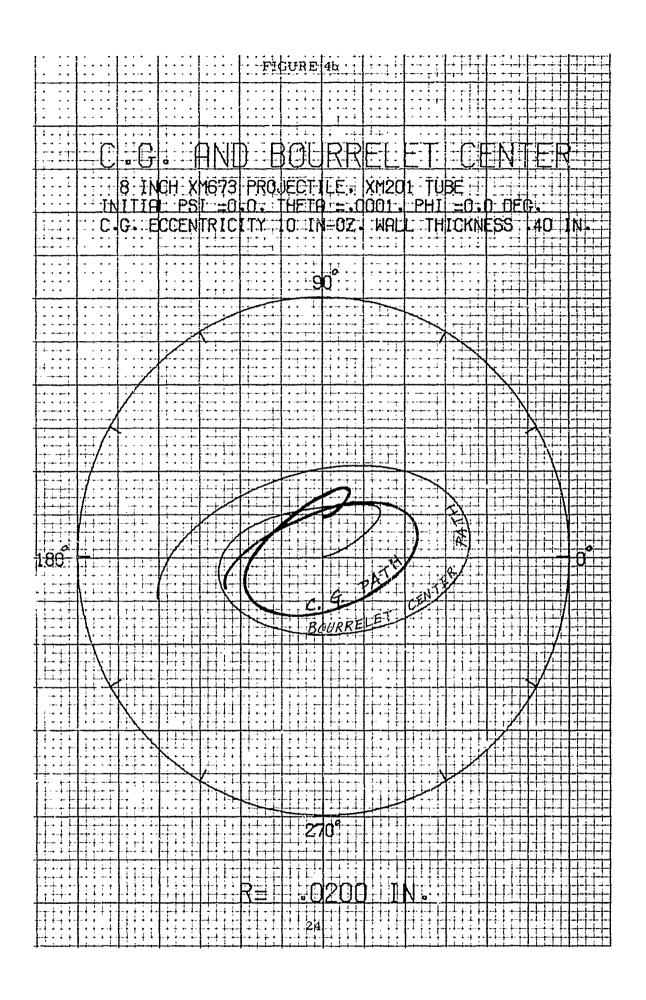
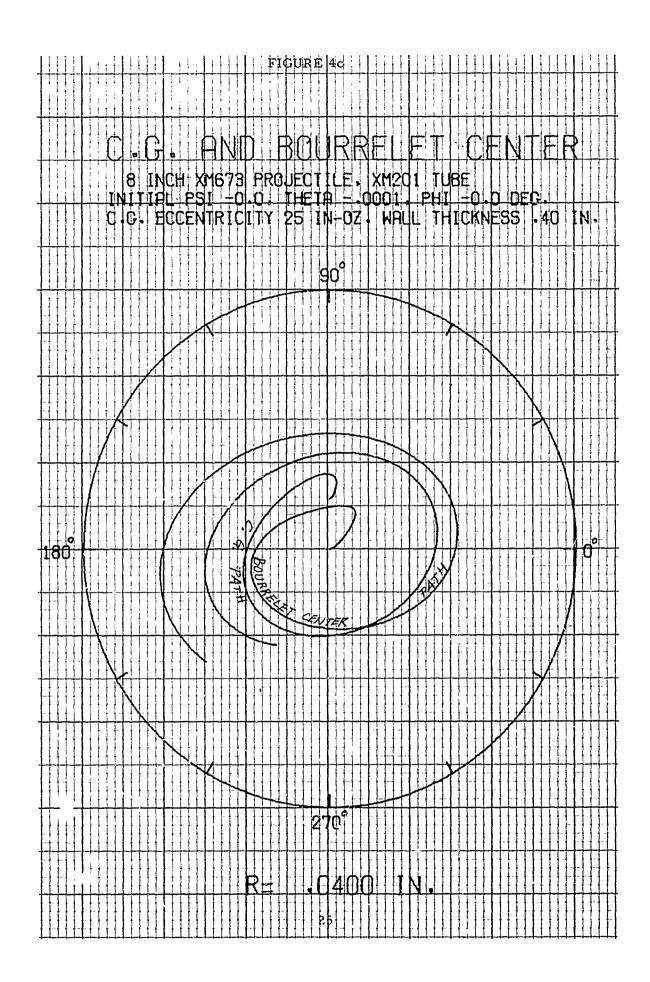


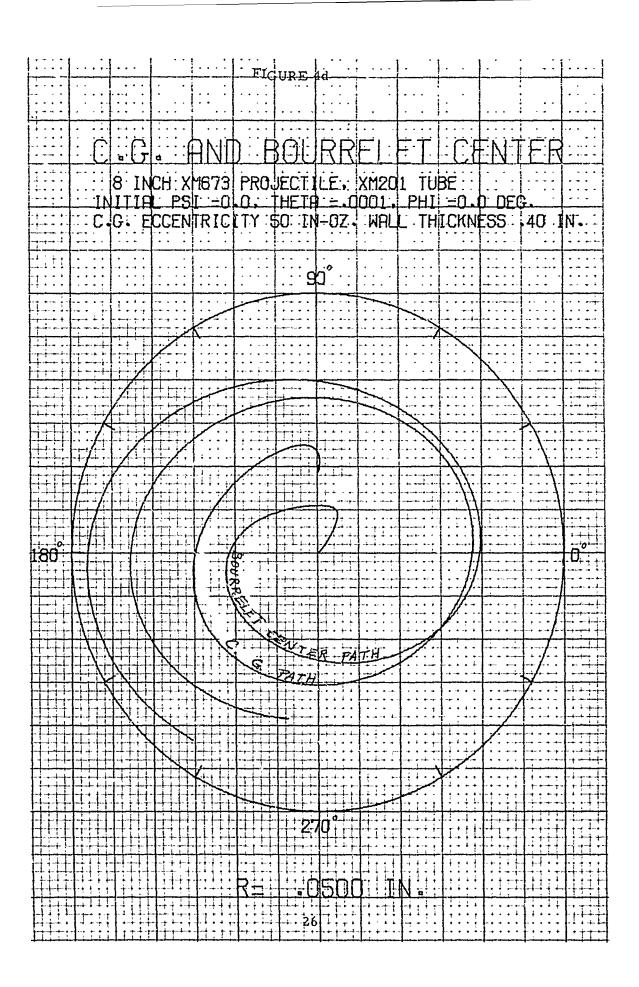
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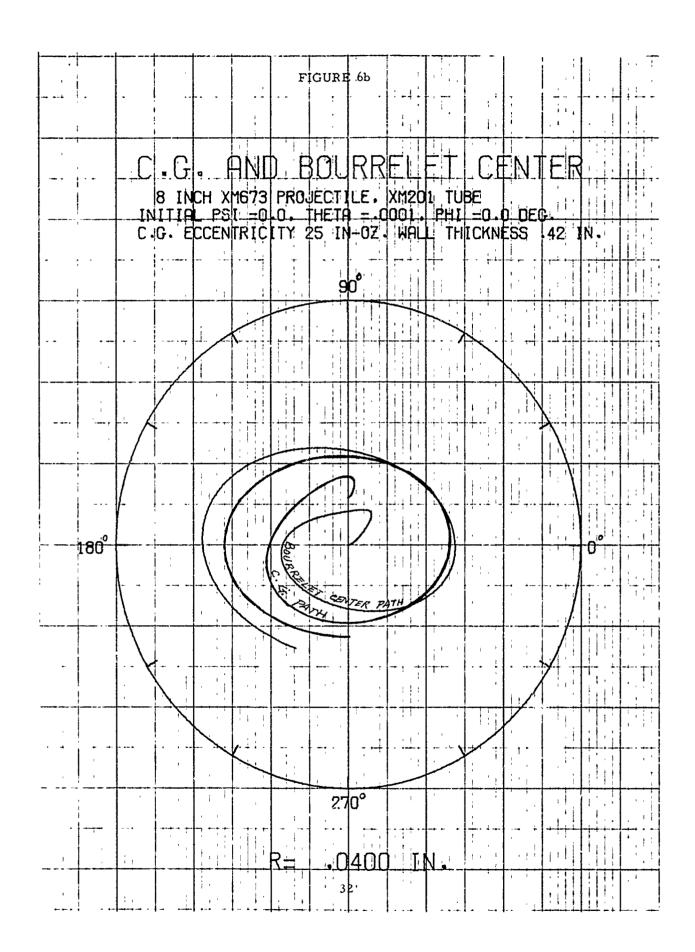
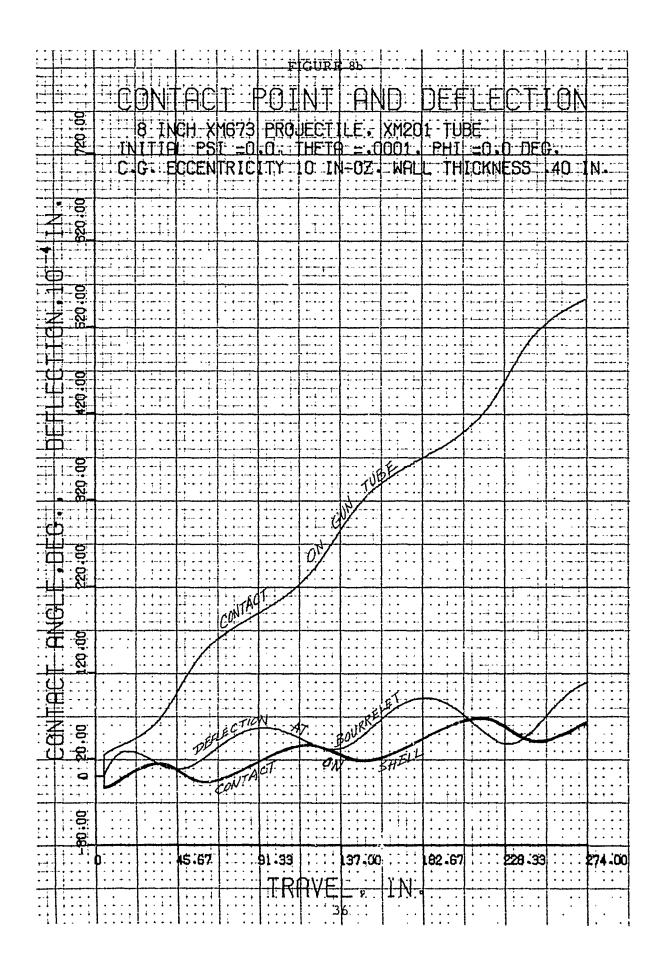


			FIGURE 7a		!		
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C.G. AND BOURRELET CENTER 8 INCH XM673 PROJECTILE, XM201 TUBE INITIA PSI = 210. IHETE = 20001. PHI = 0.0 DEG. C.G. ECCENTRICITY 25 IN-0Z. WALL THICKNESS 40 IN. C.G. TO TRIVING BAND DISTANCE REDUCED TO 4 ORIGINAL VALUE 90° 270° 270°		FIGUF	RE 7b			
C.G. ECCENTRICITY 25 IN-07. WALL THICKNESS 40 IN. C.G. TO TREVENC BAND DESTANCE-REQUEED TO 1/2 ORIGINAL VALUE 90 0 0 0 0 0 0 0 0 0 0 0 0	C G	CH XM673 PROJ		XM201 TUE	BE:	ER
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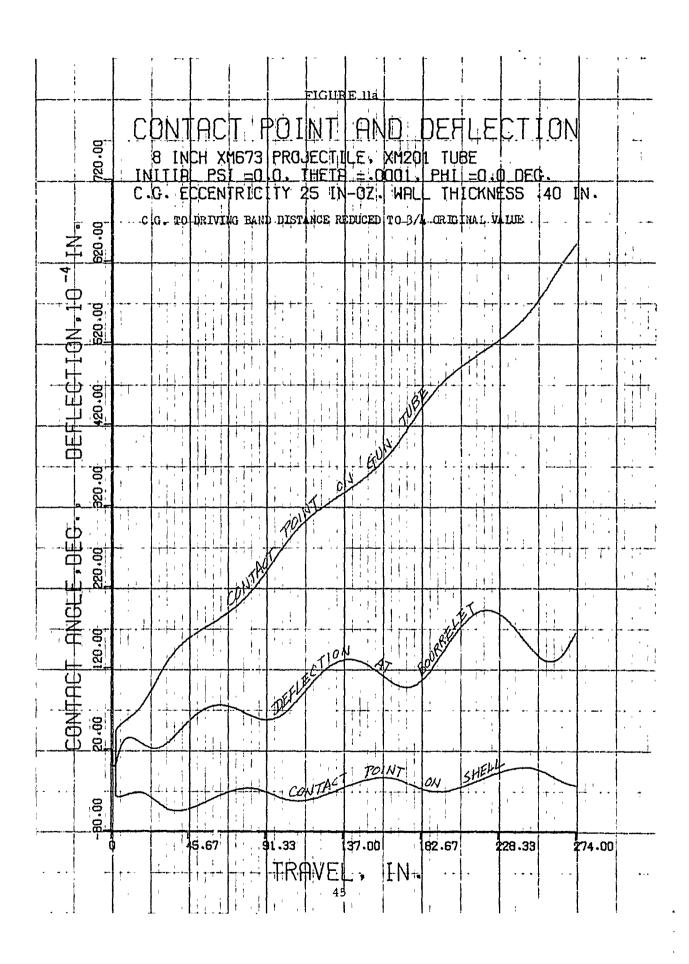
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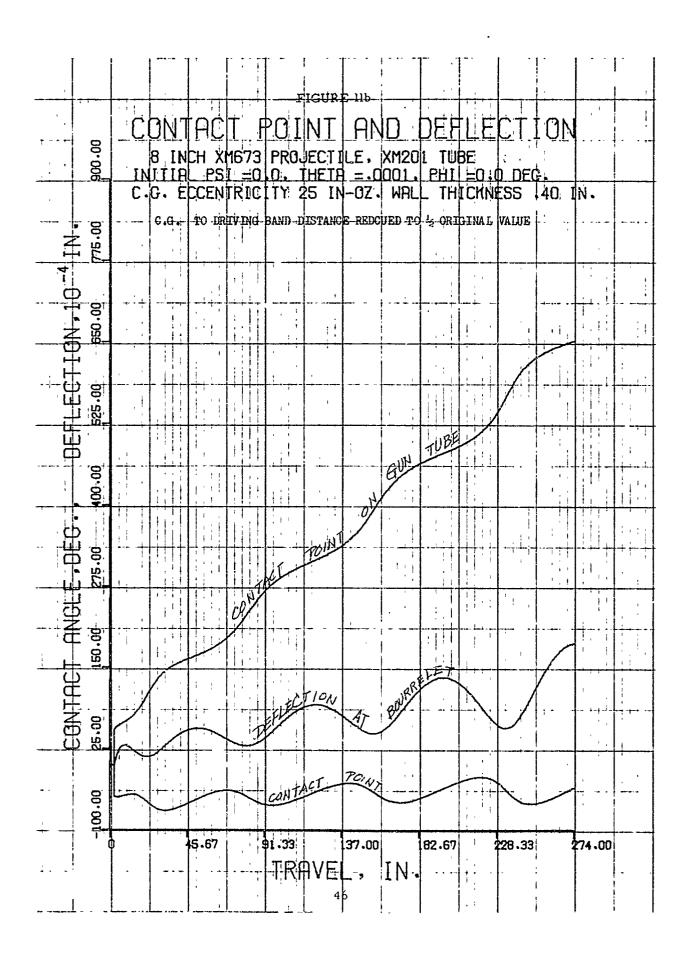
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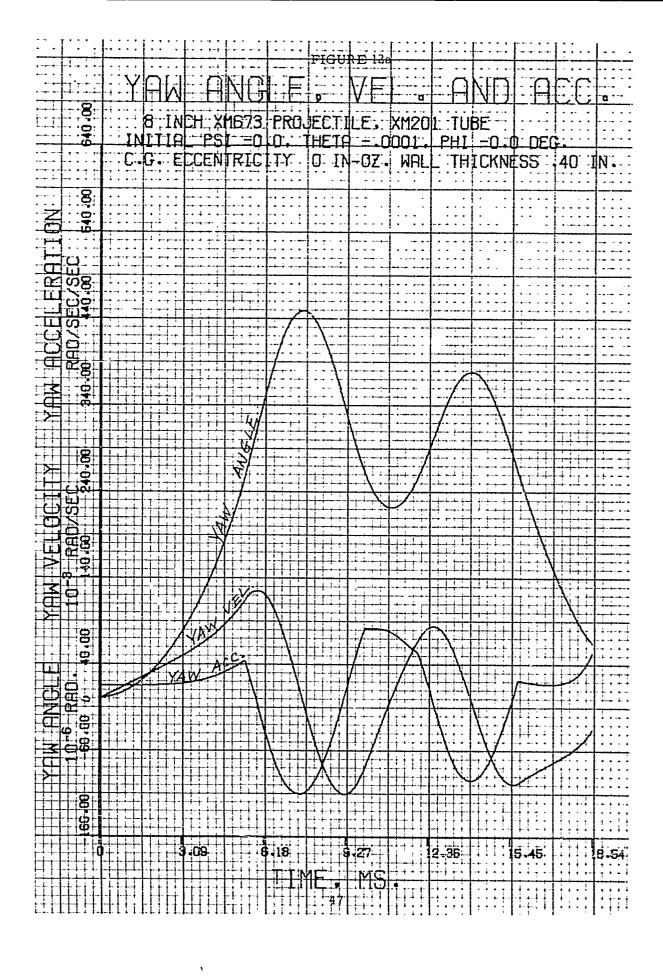
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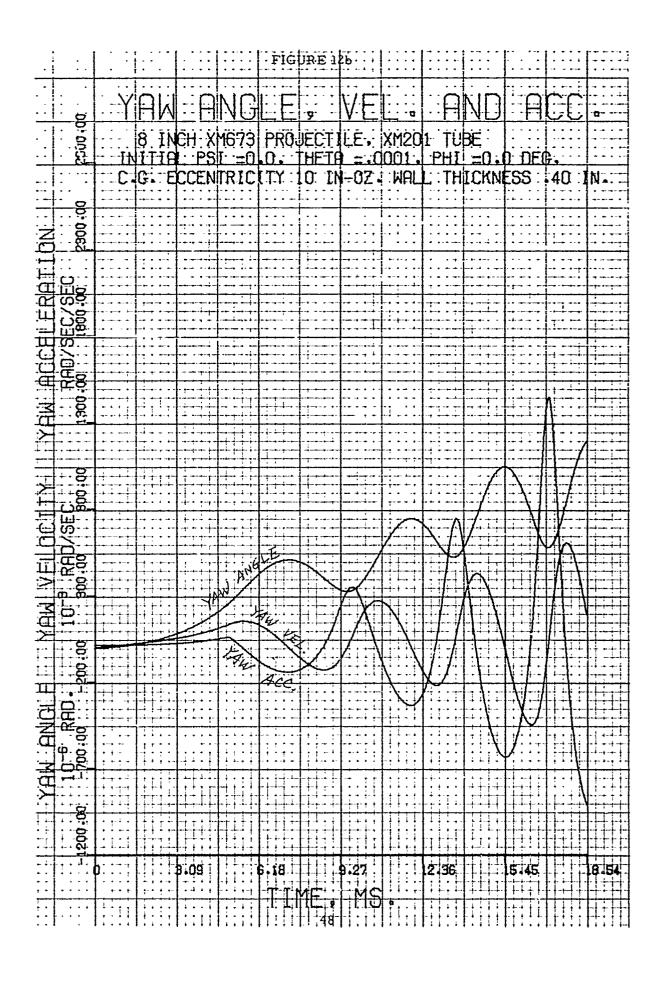
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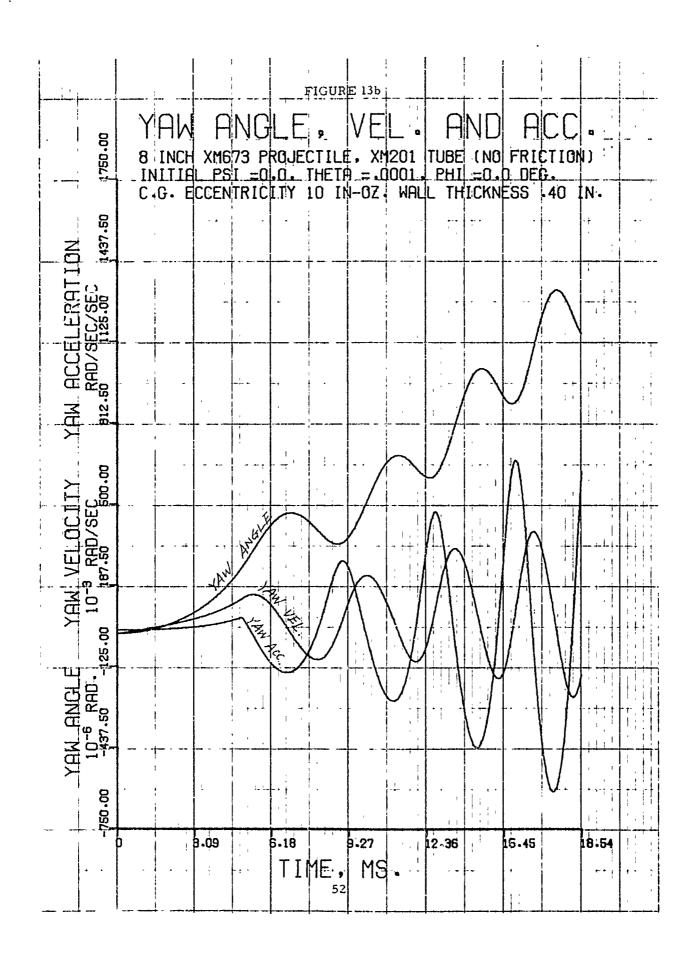
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			FIGURE 1	4b			
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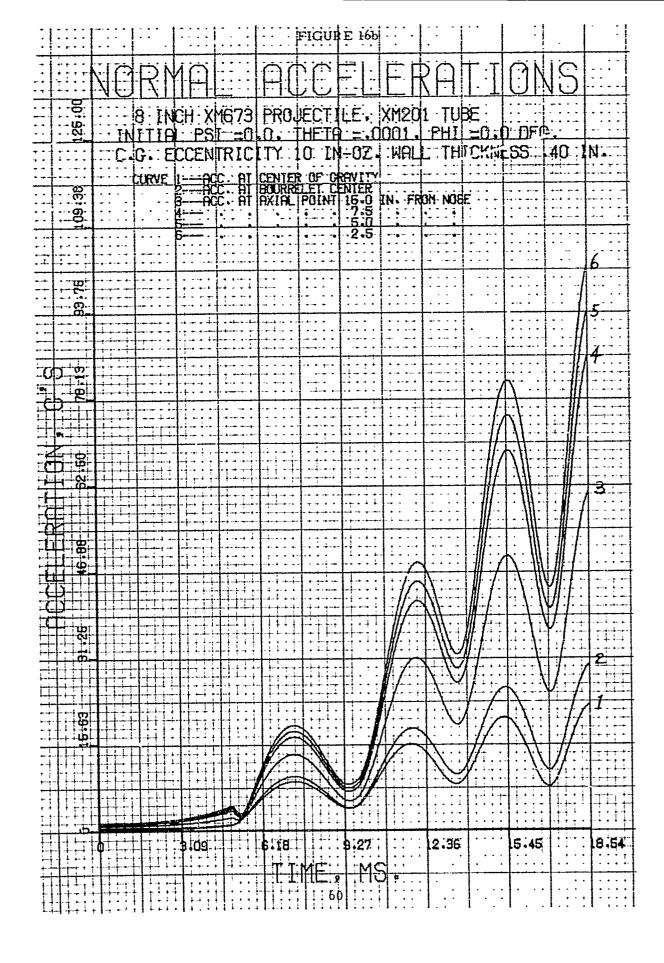
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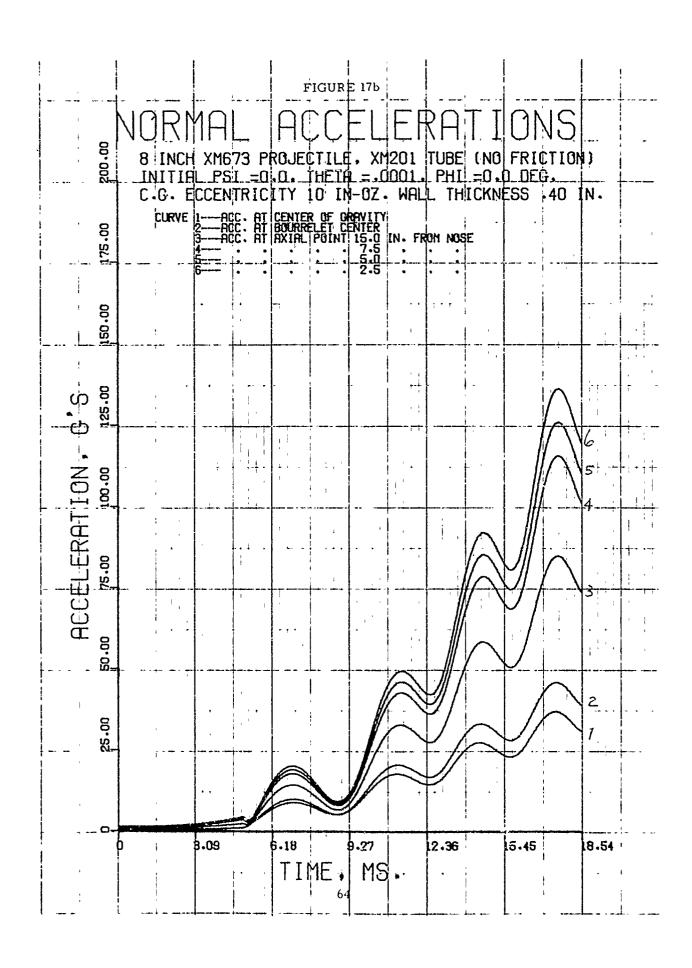
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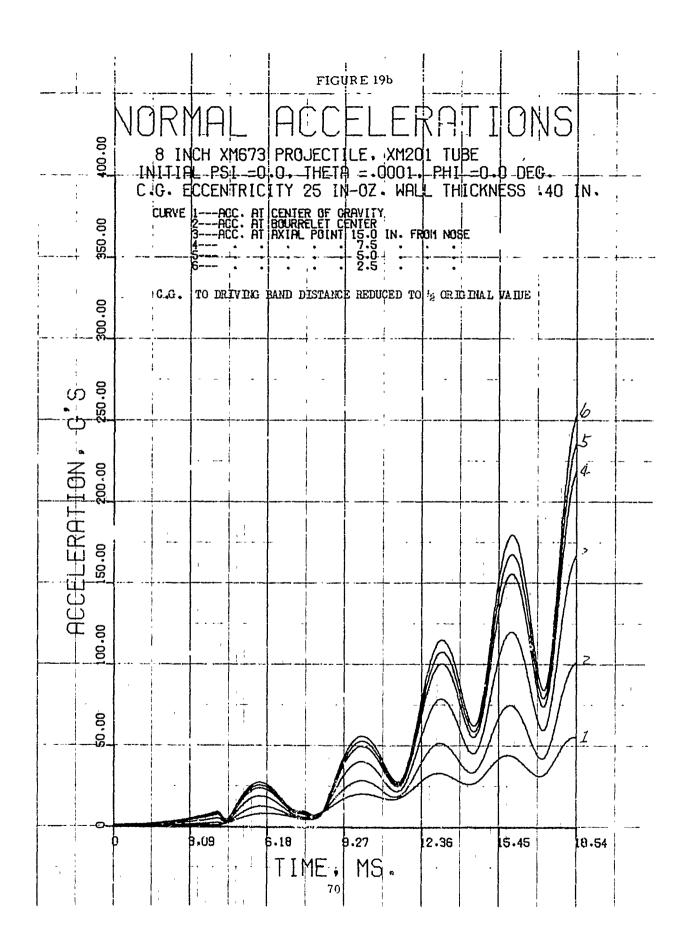
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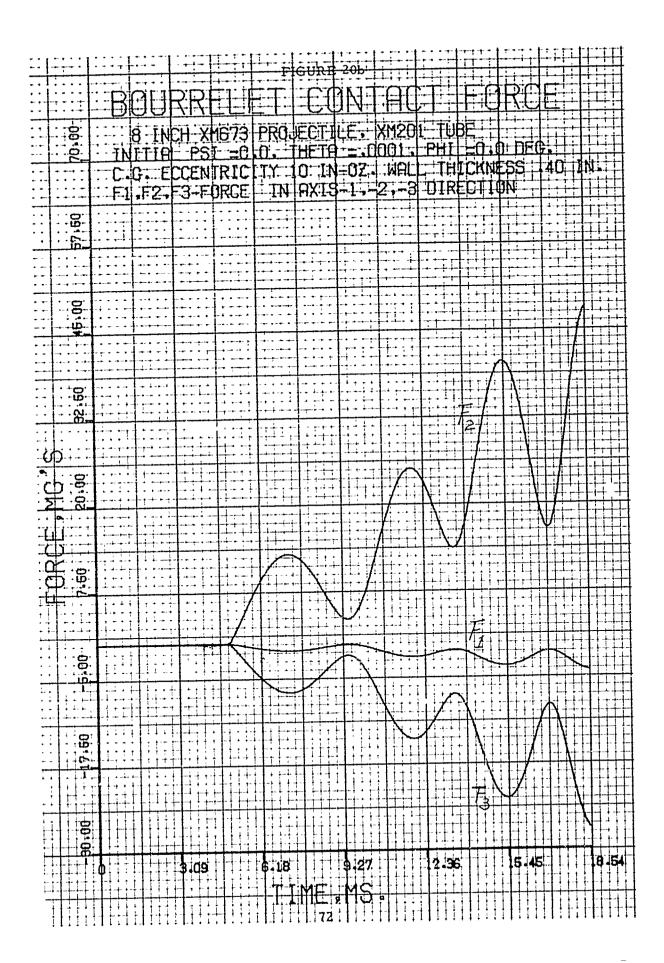
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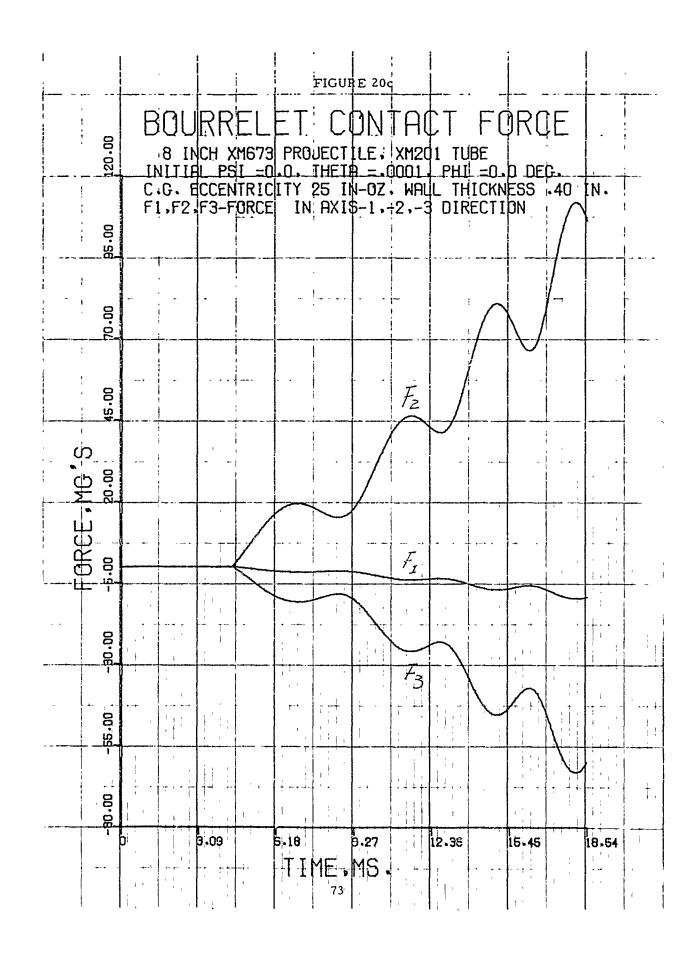
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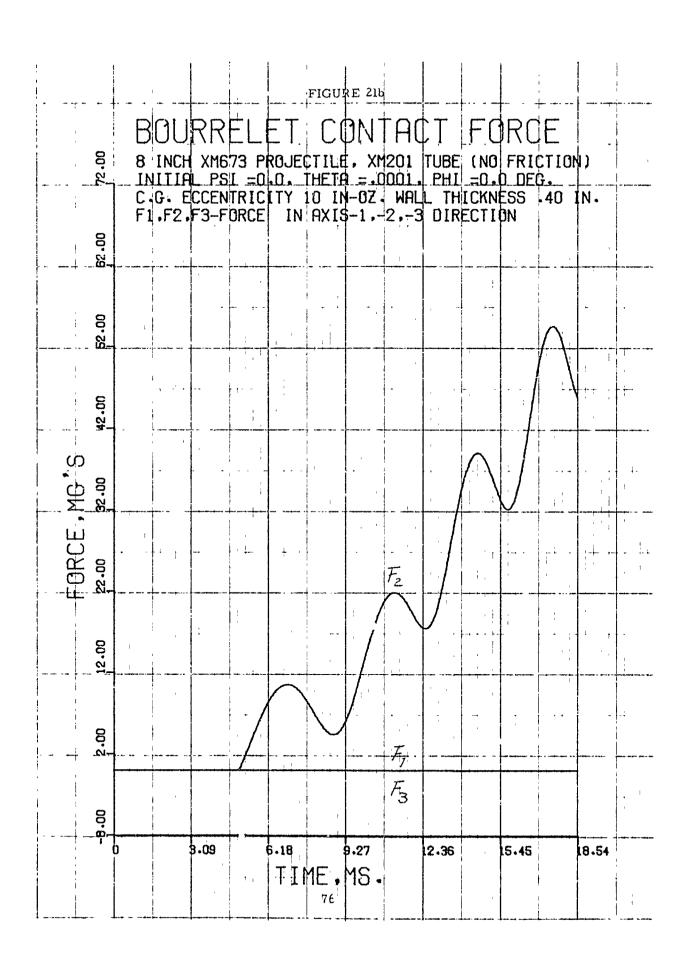


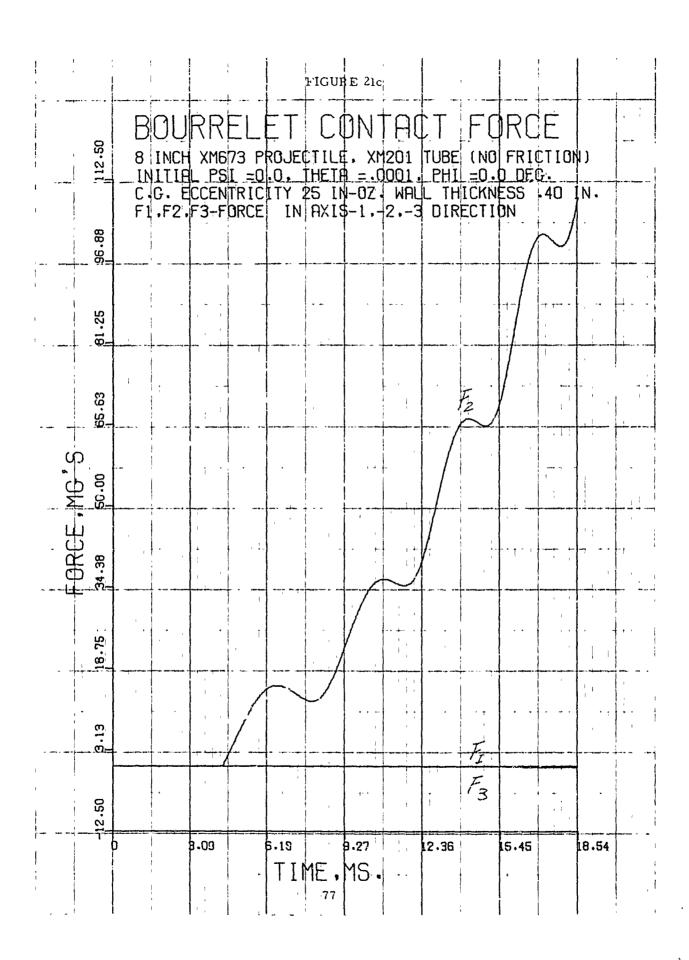


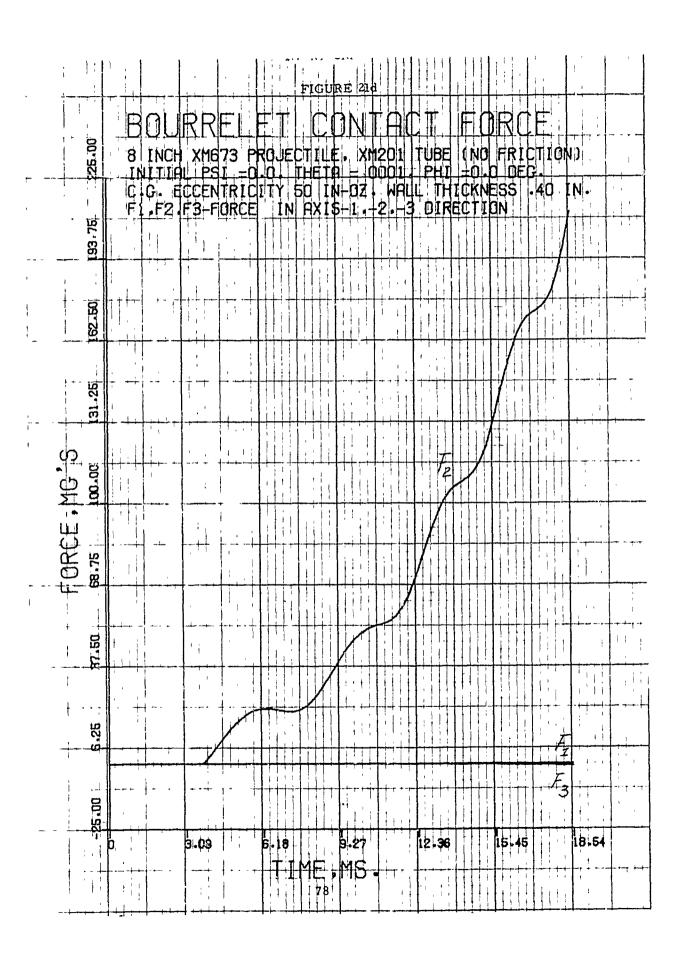
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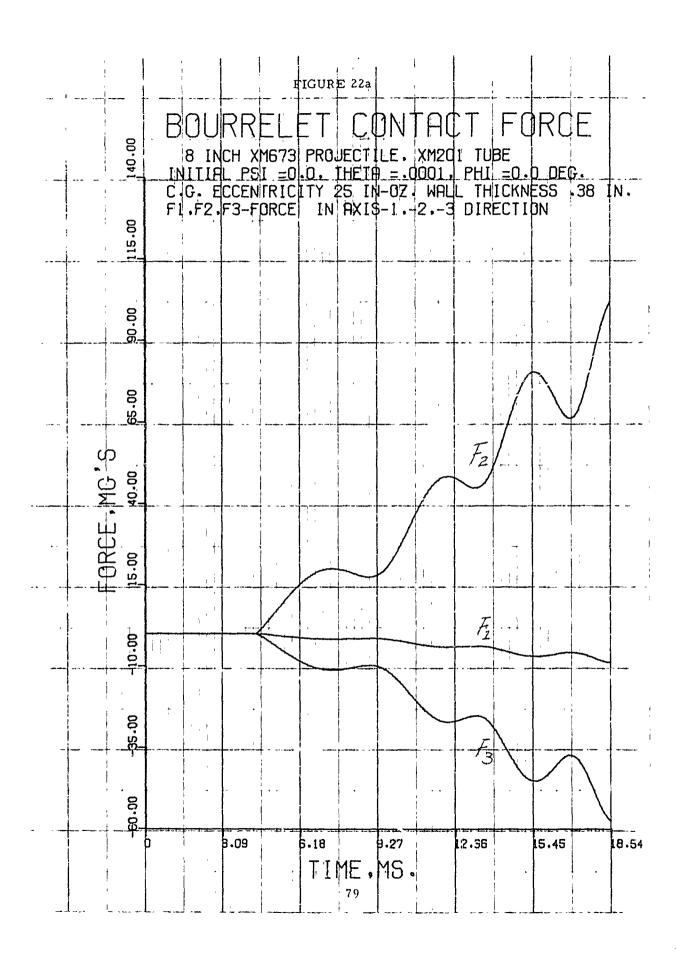


		FIGURE 22h
	120-00	BOURRELET CONTACT FORCE 8 INCH XM873 PROJECTILE, XM201 TUBE INITIAL PSU =0.0, THETH = .0001, PHI =0.0 DEG.
	95.00	C.G. ECCENTRICITY 25 IN-0Z. WALL THICKNESS 42 IN. F1.F2.F3-FORCE IN AXIS-123 DIRECTION
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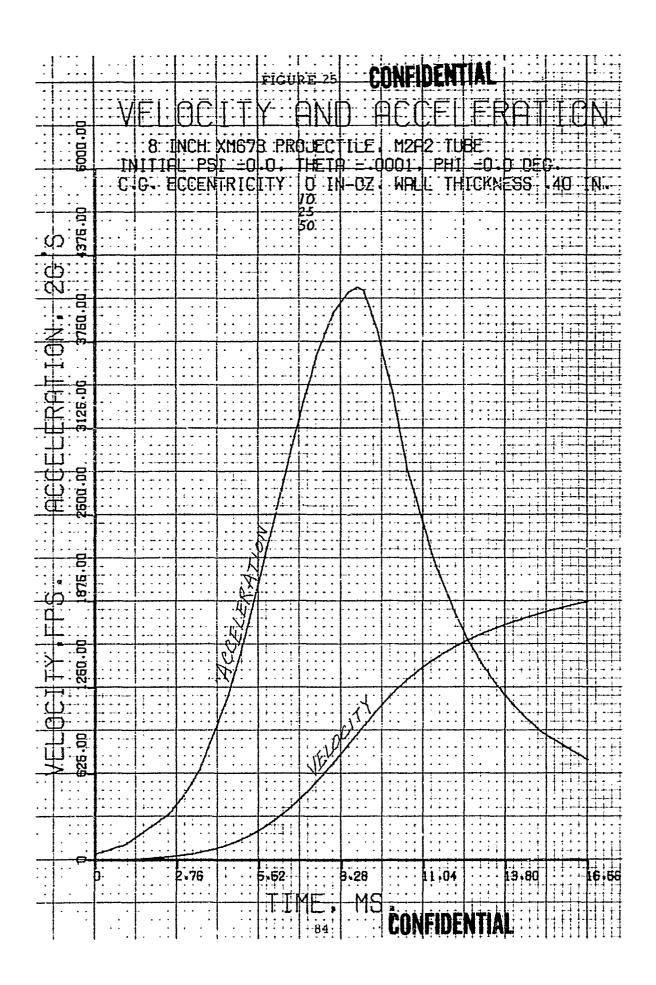
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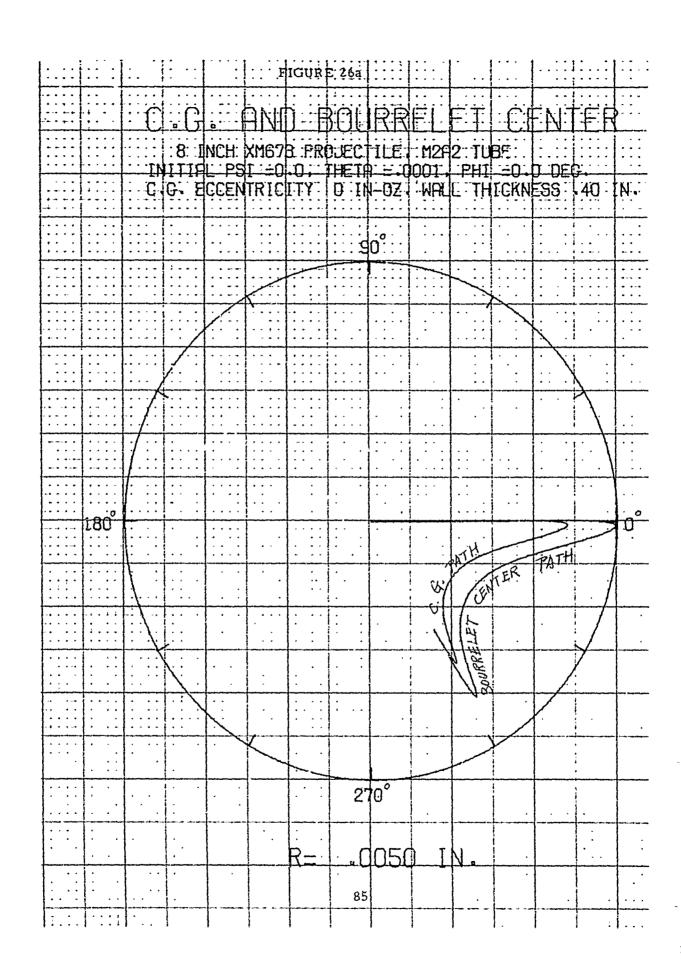
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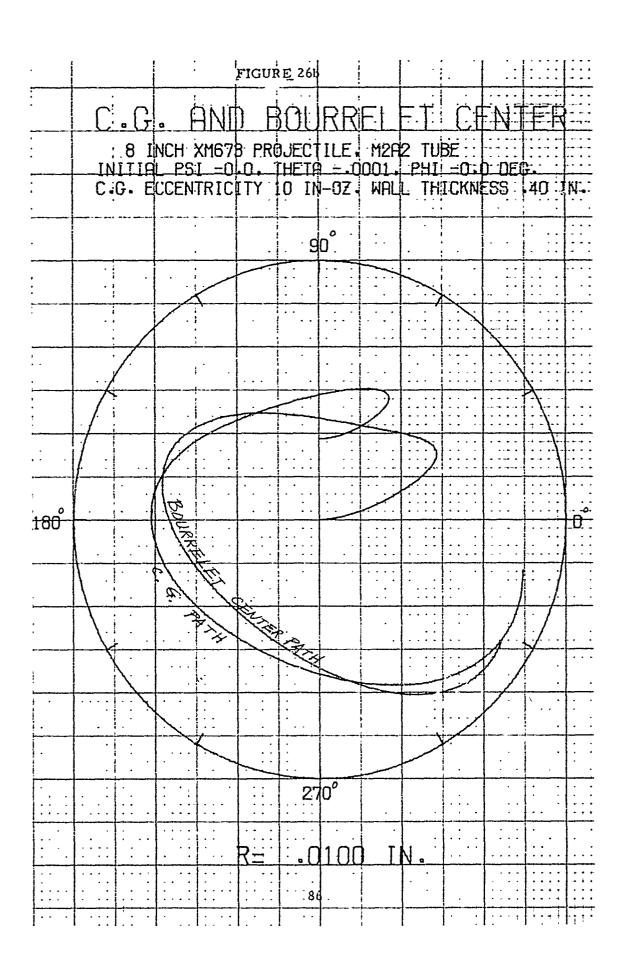
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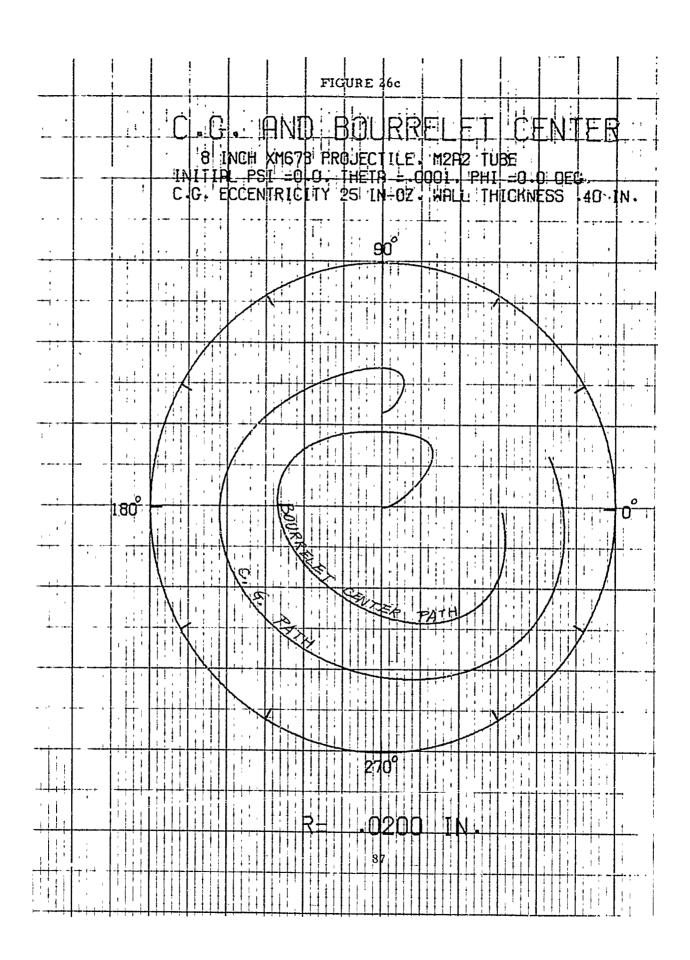
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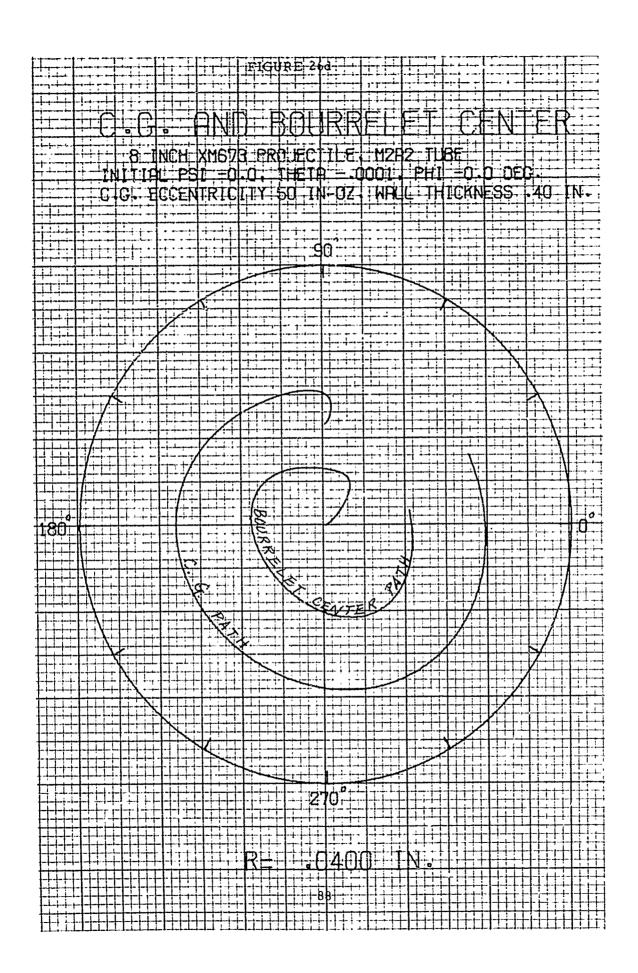
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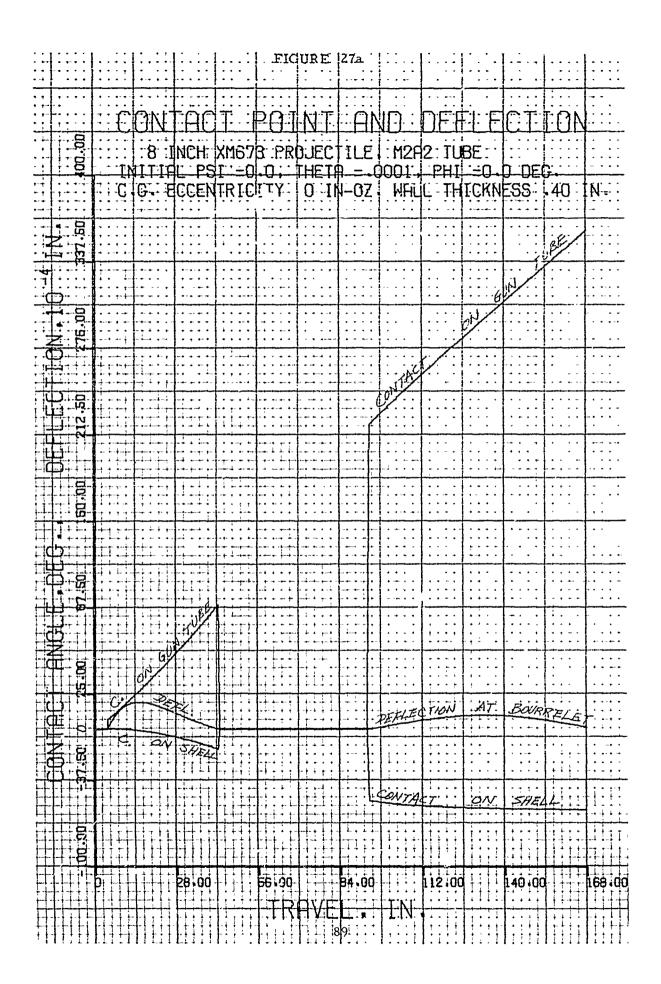












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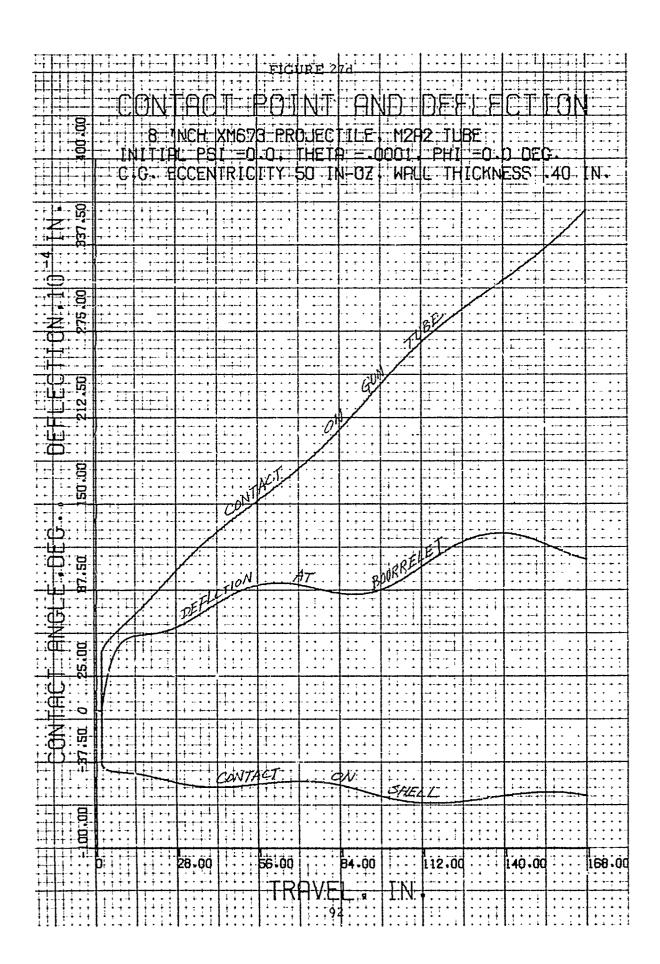
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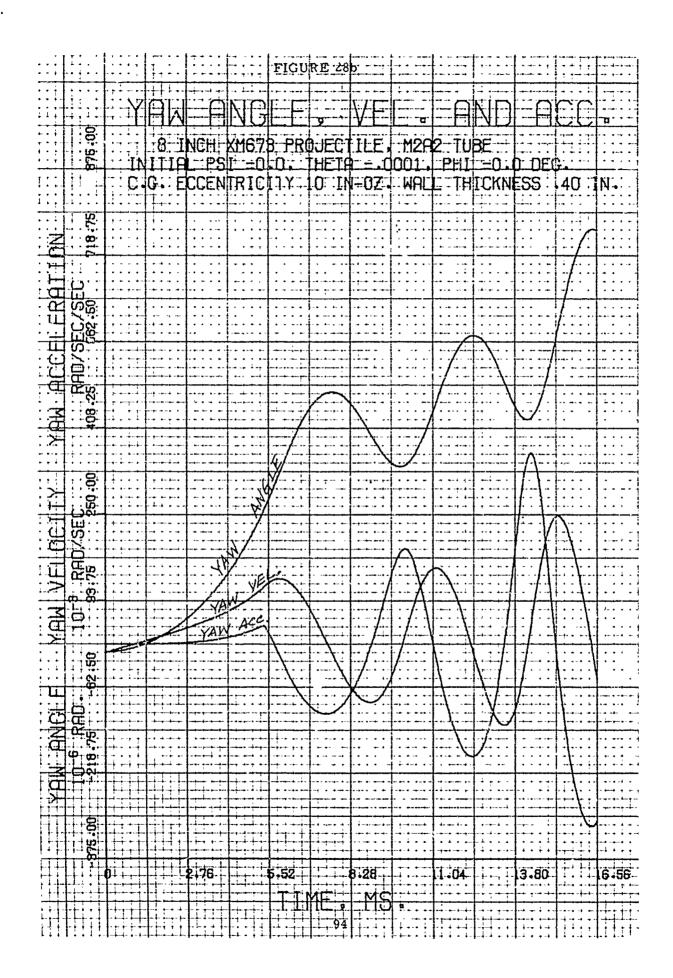
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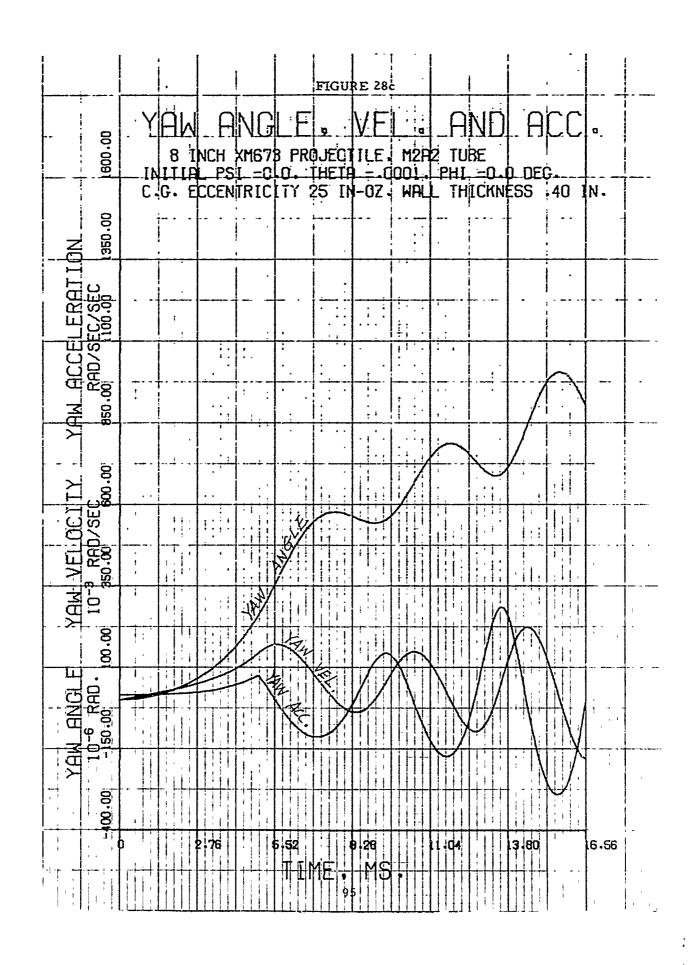
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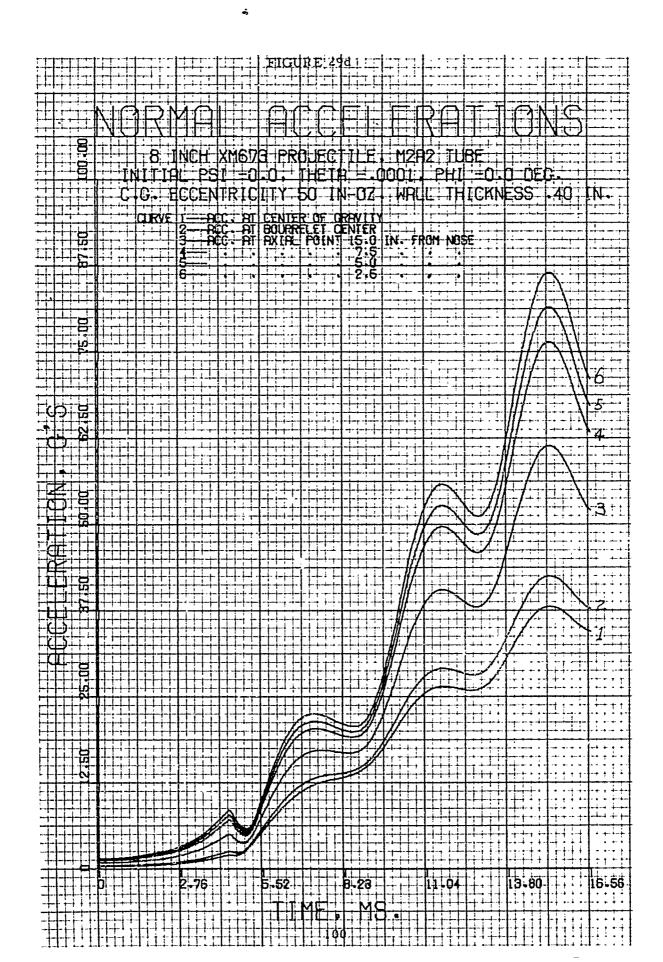


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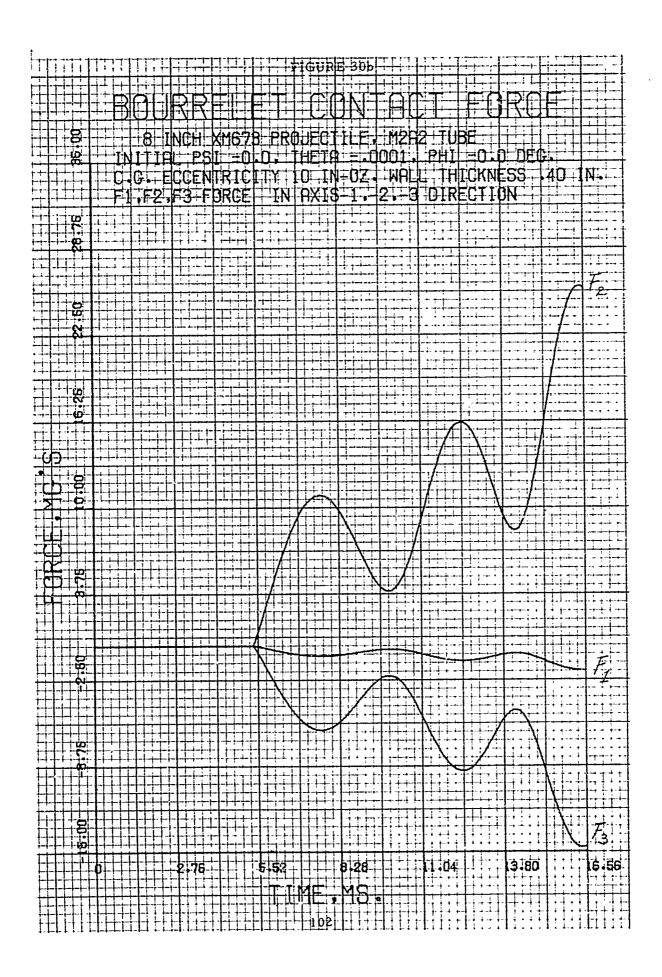
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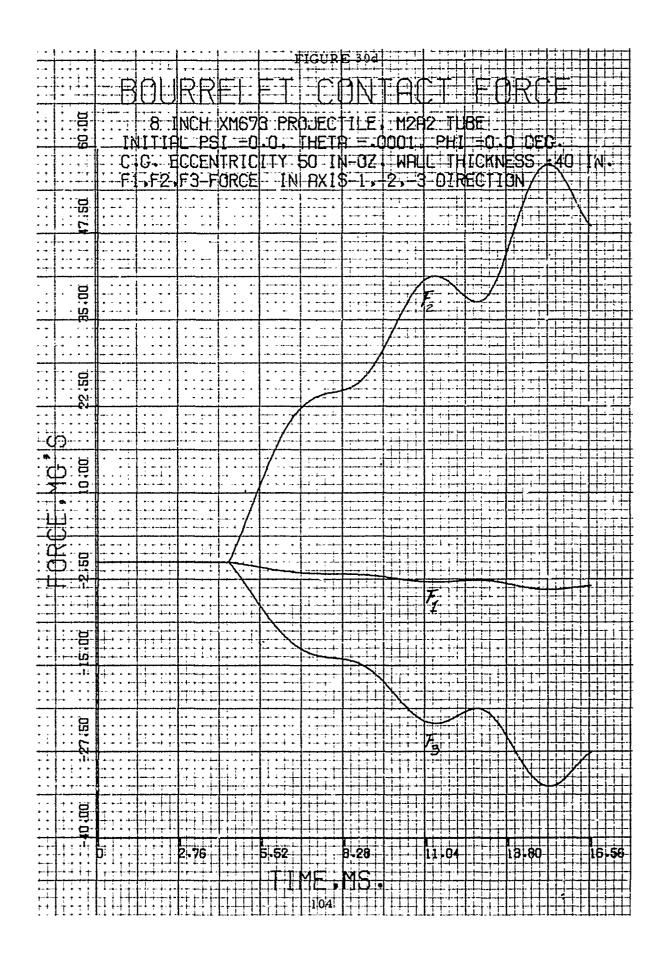
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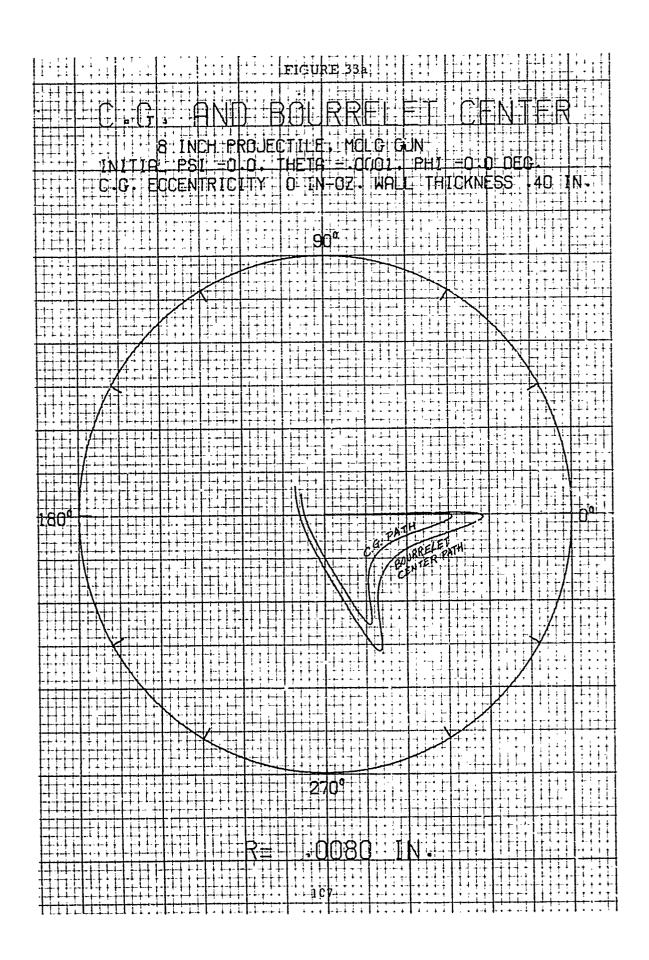
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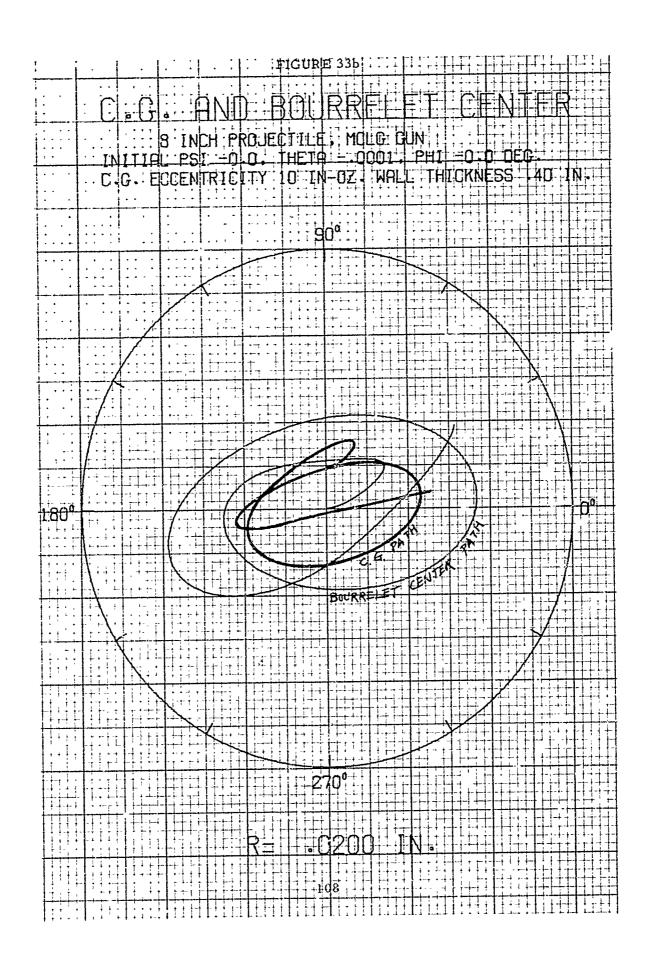


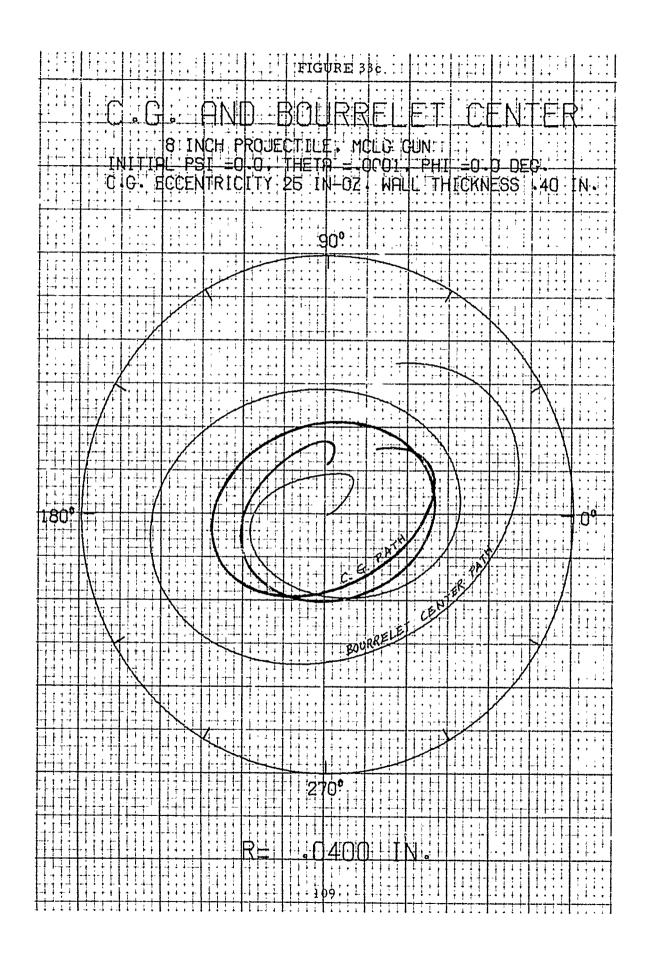
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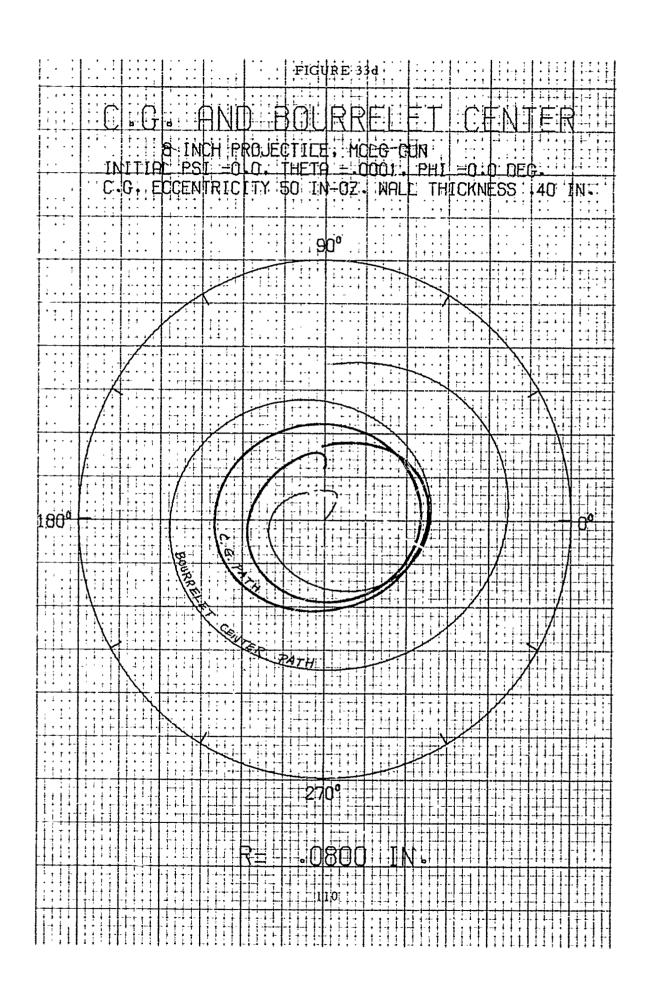


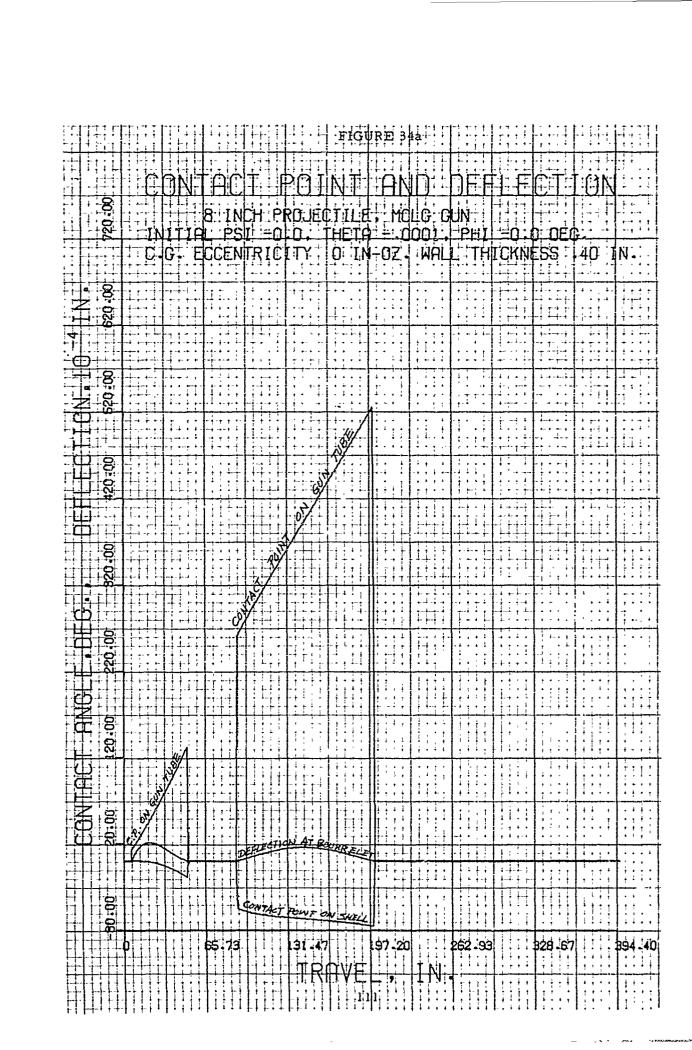


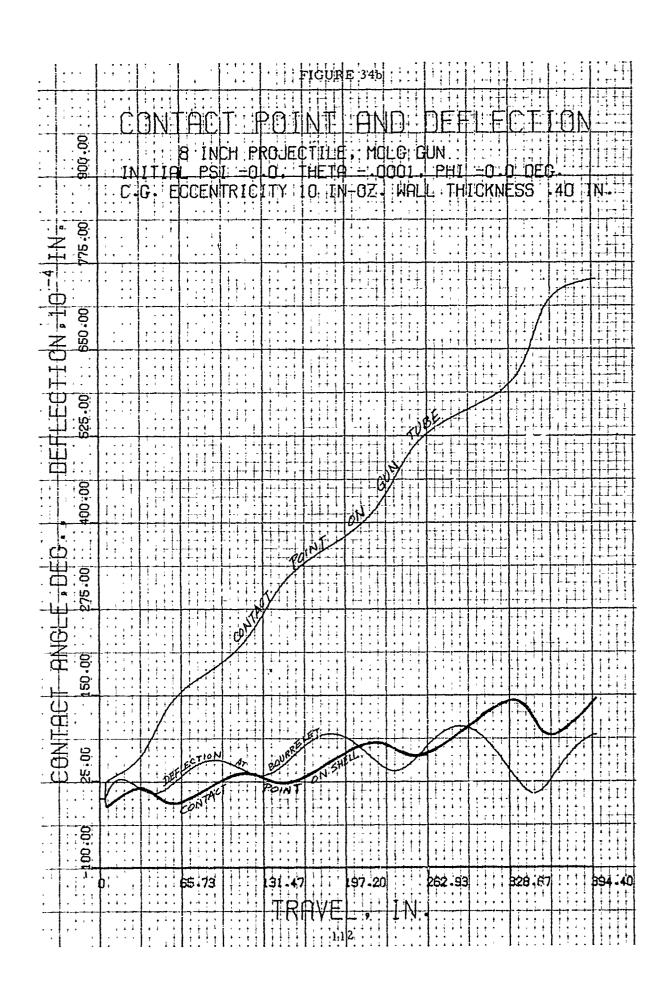


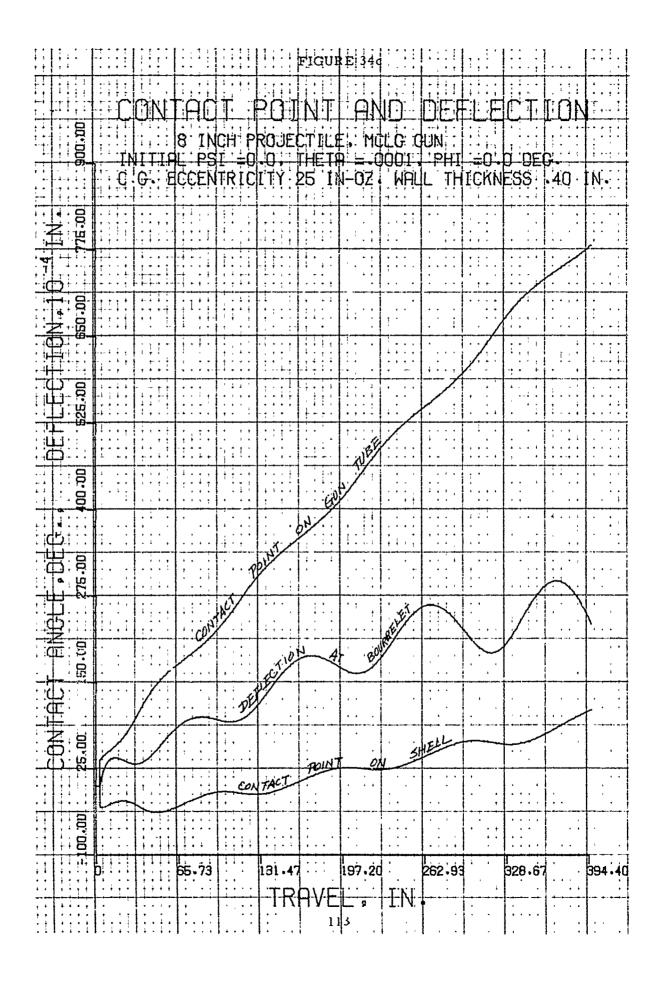
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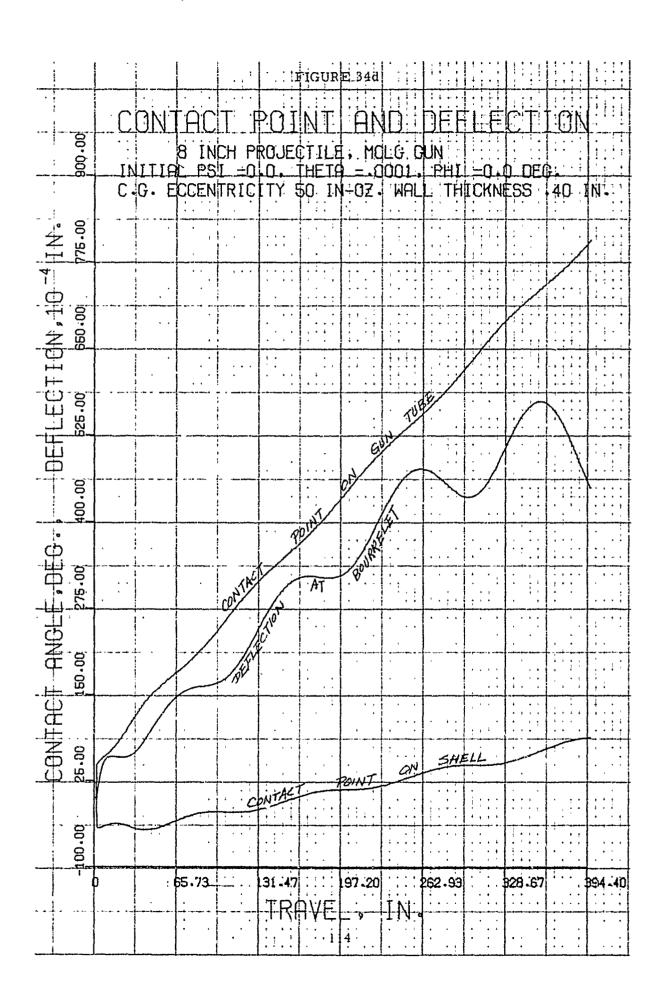
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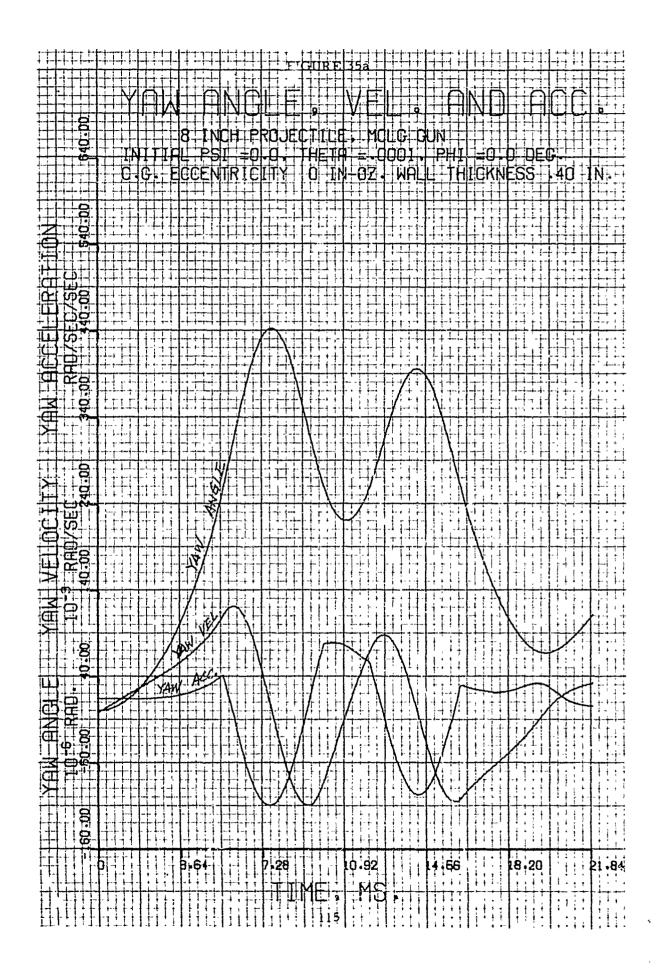


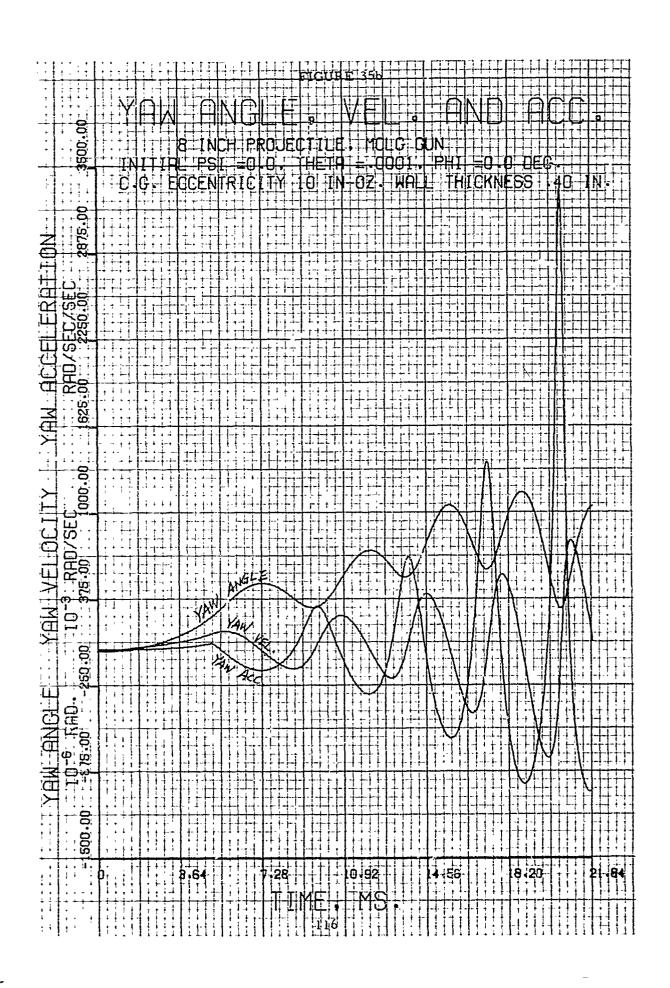




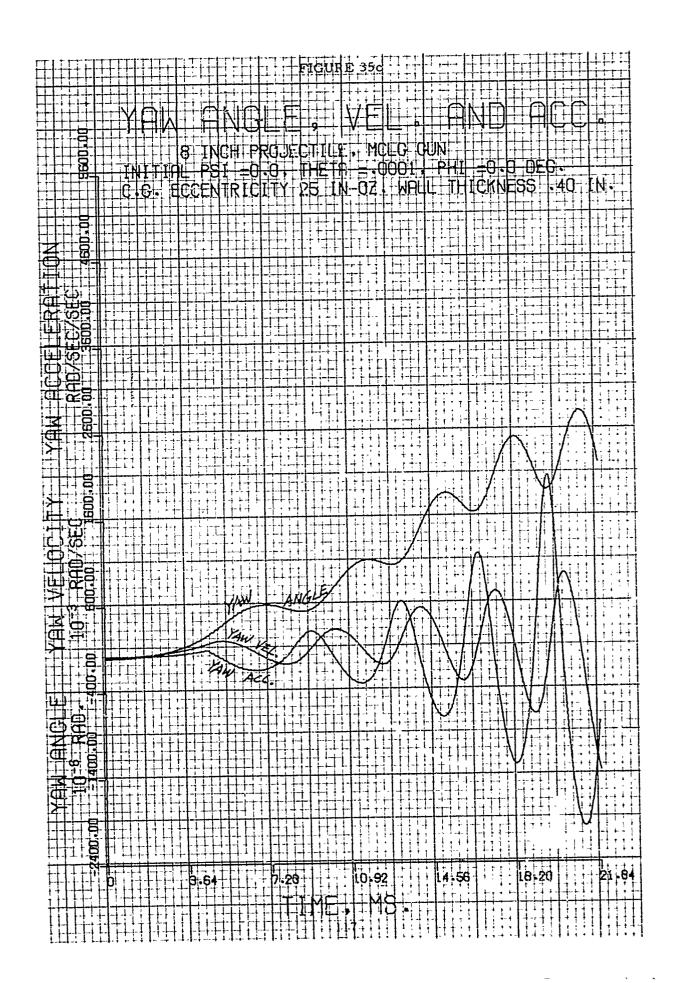


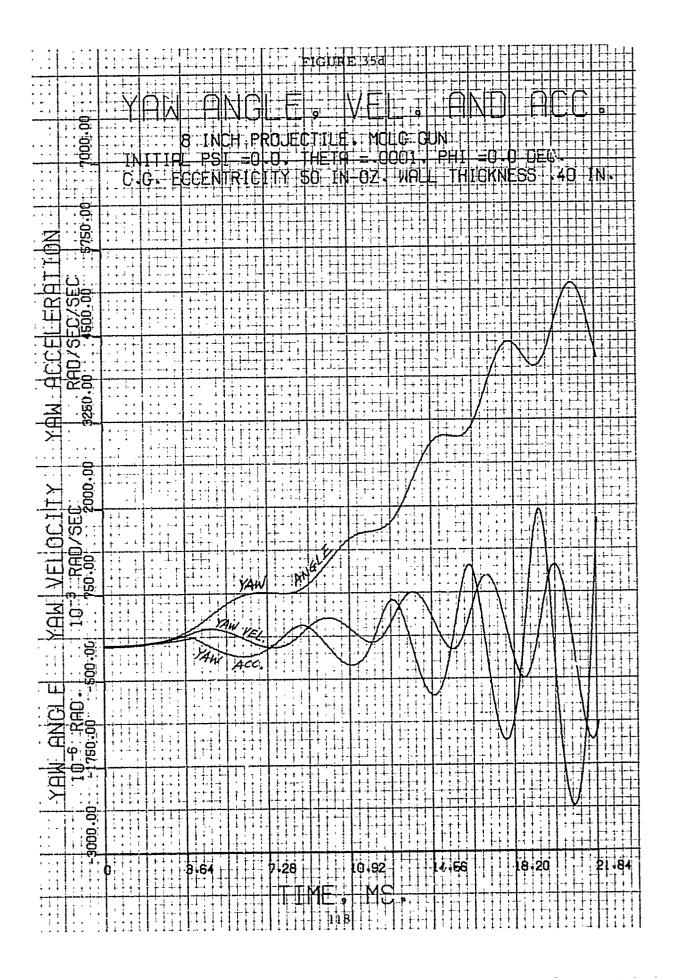


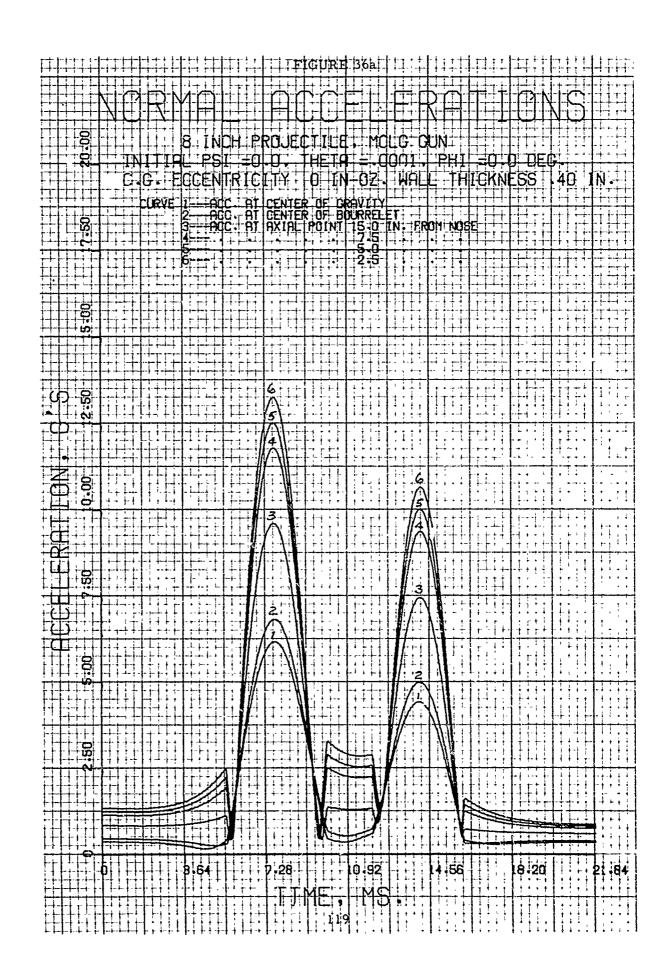


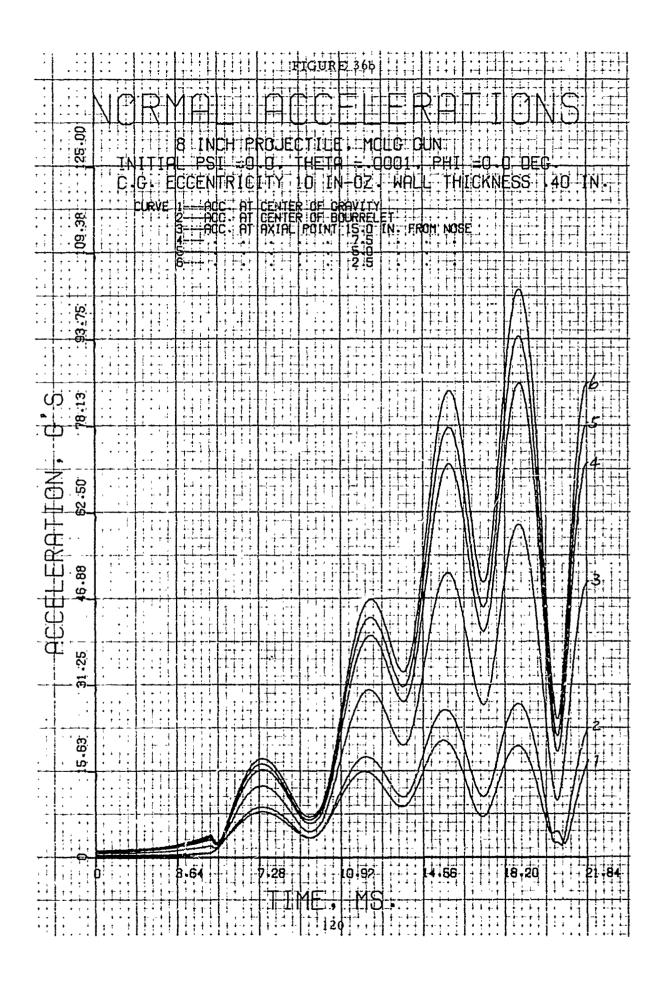


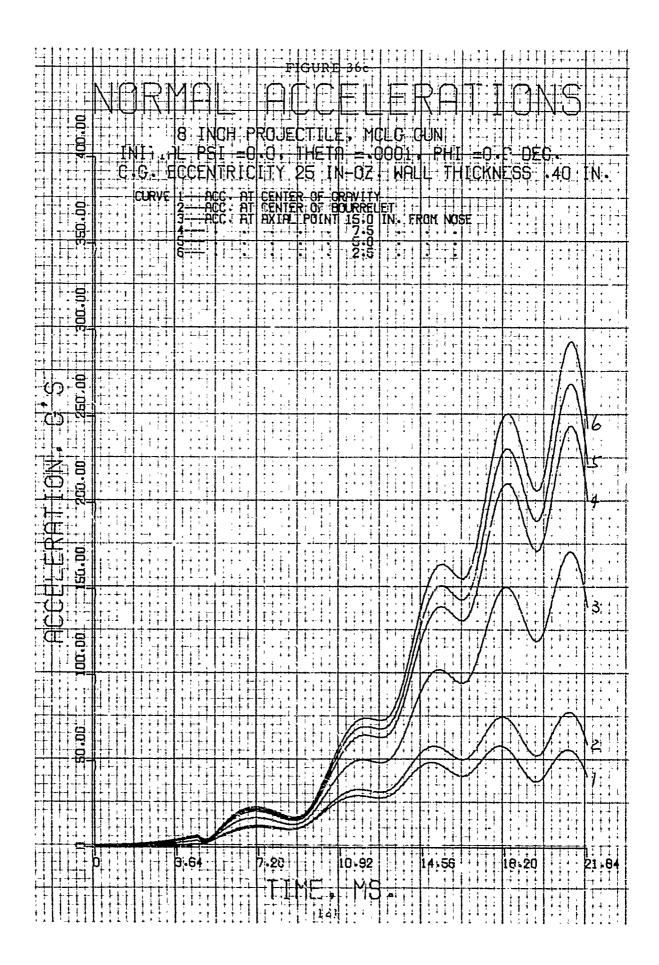
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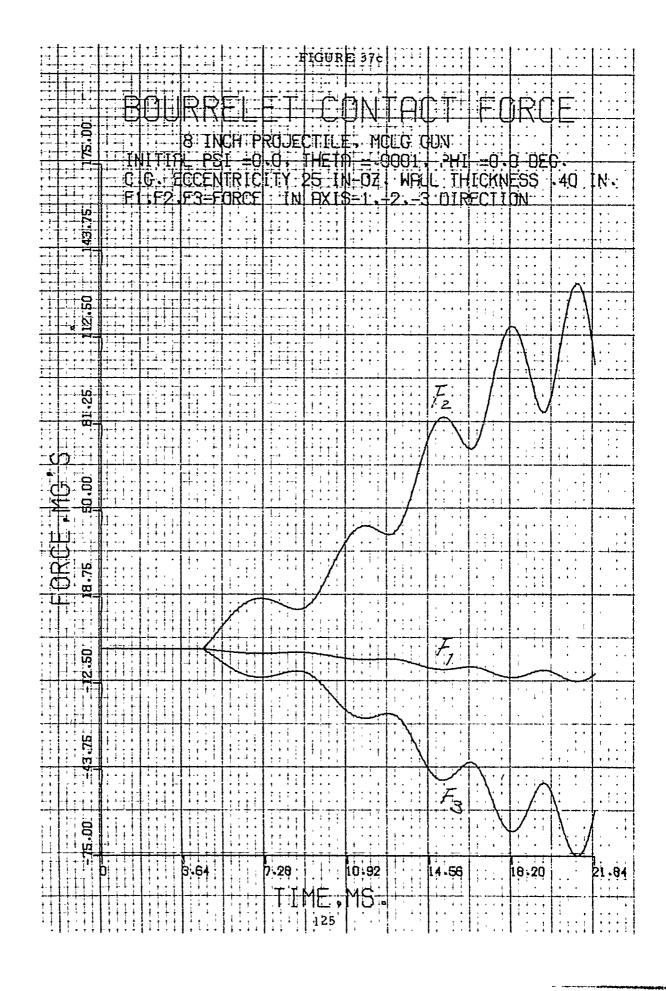
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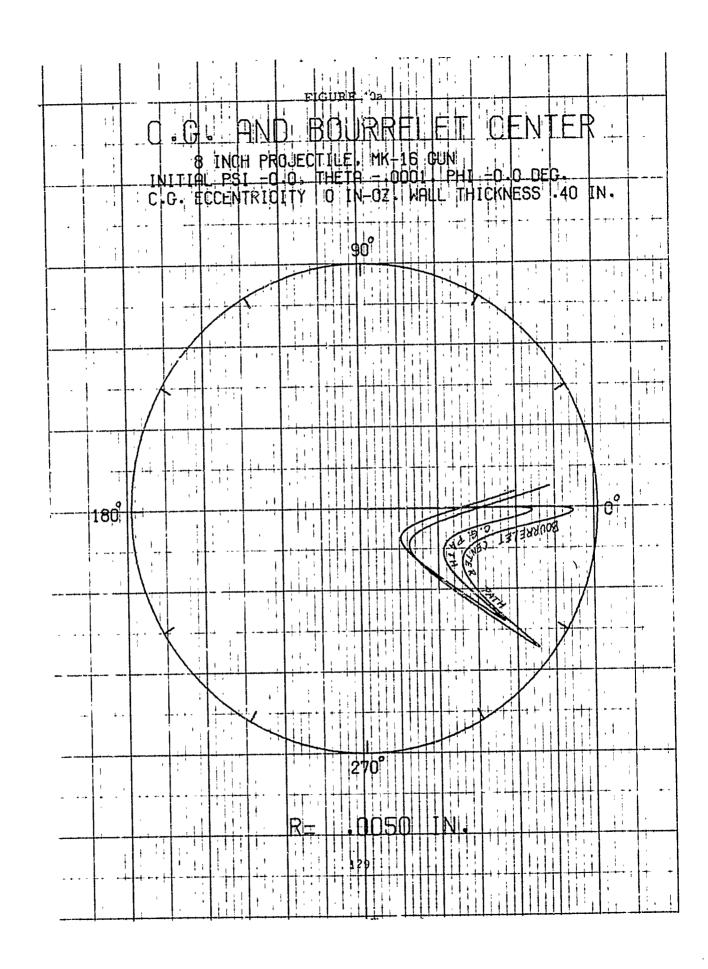
MK-16 GUN

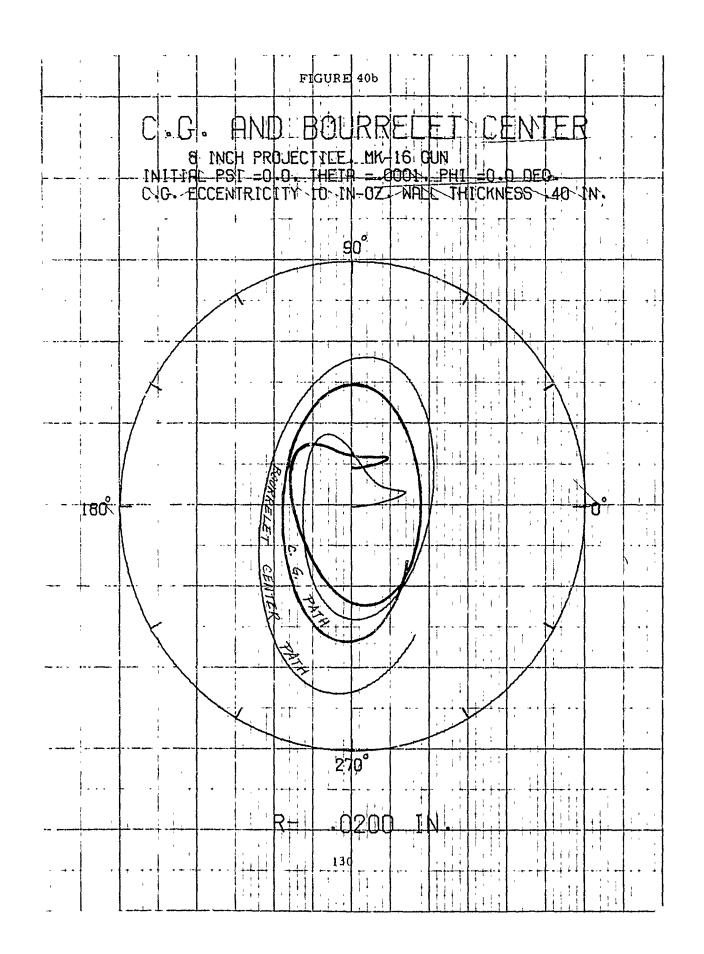
	FIGURE 38' CONFIDENTIAL
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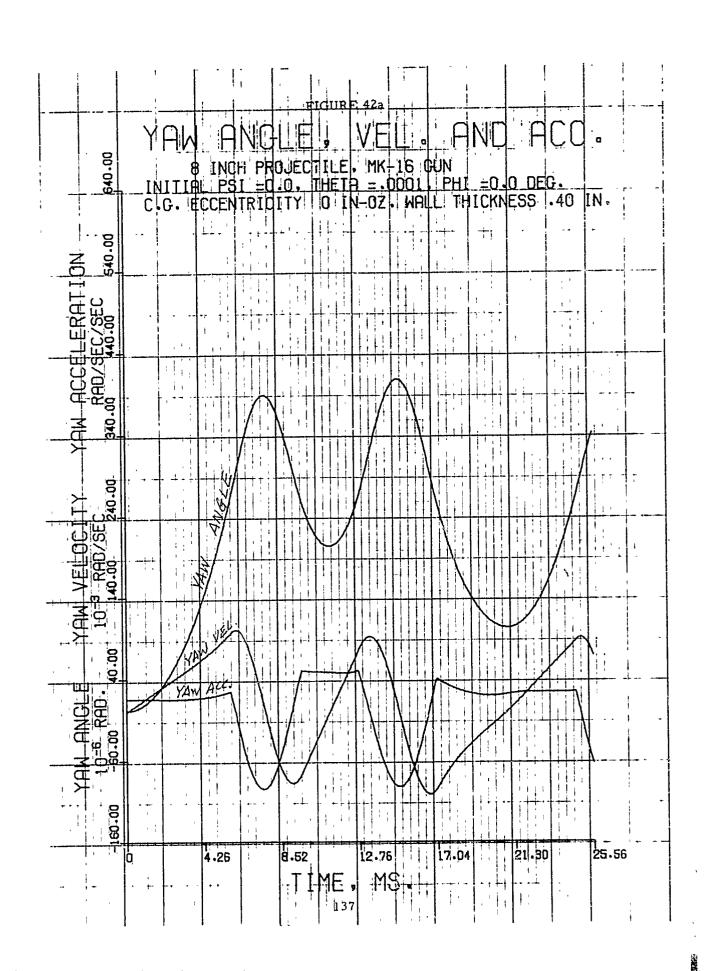
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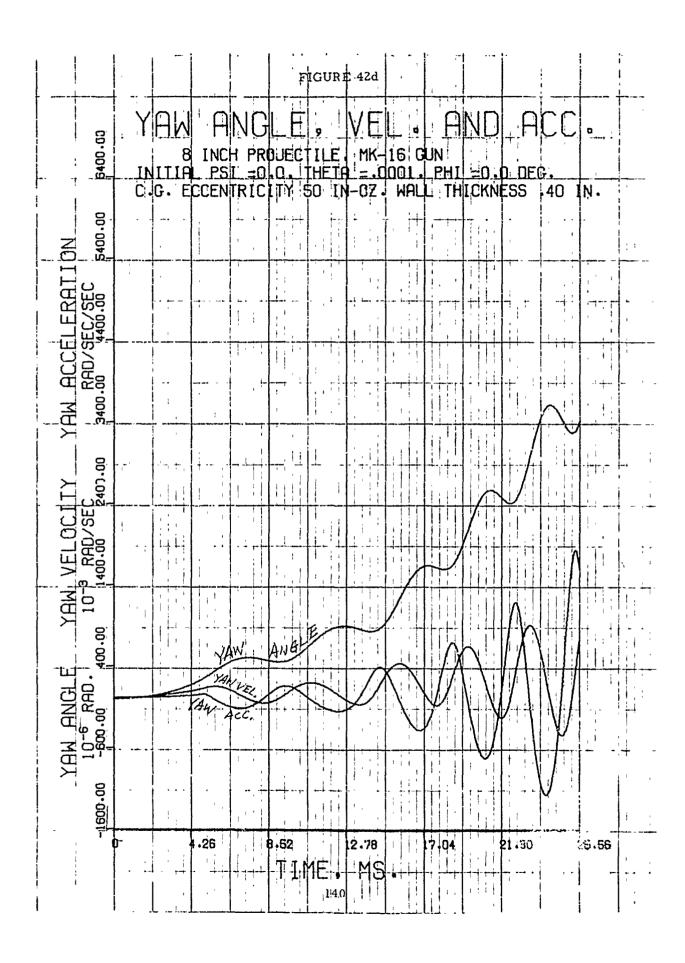
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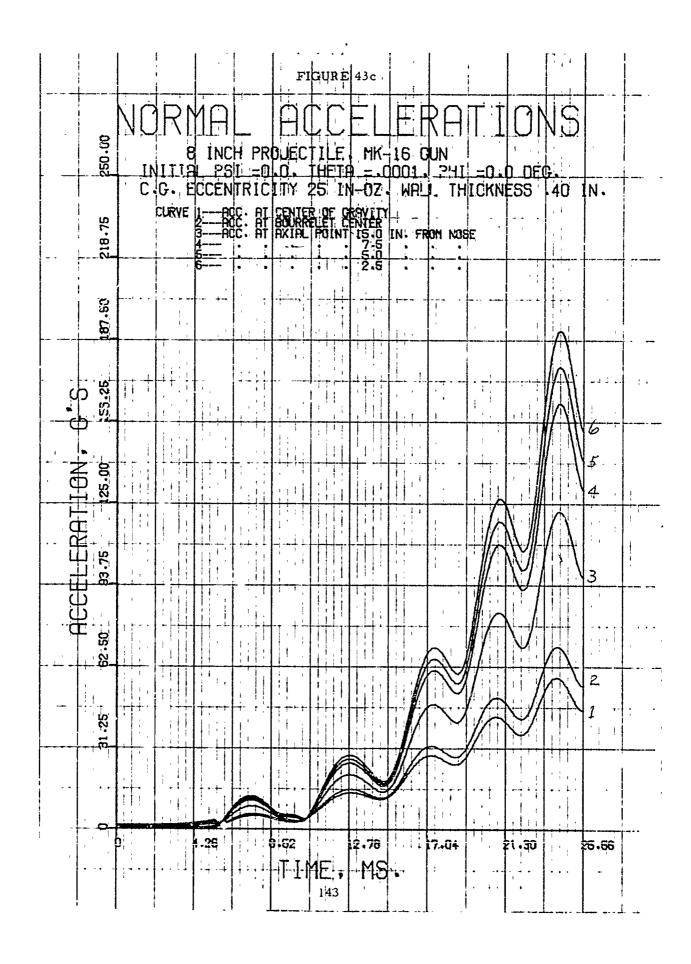
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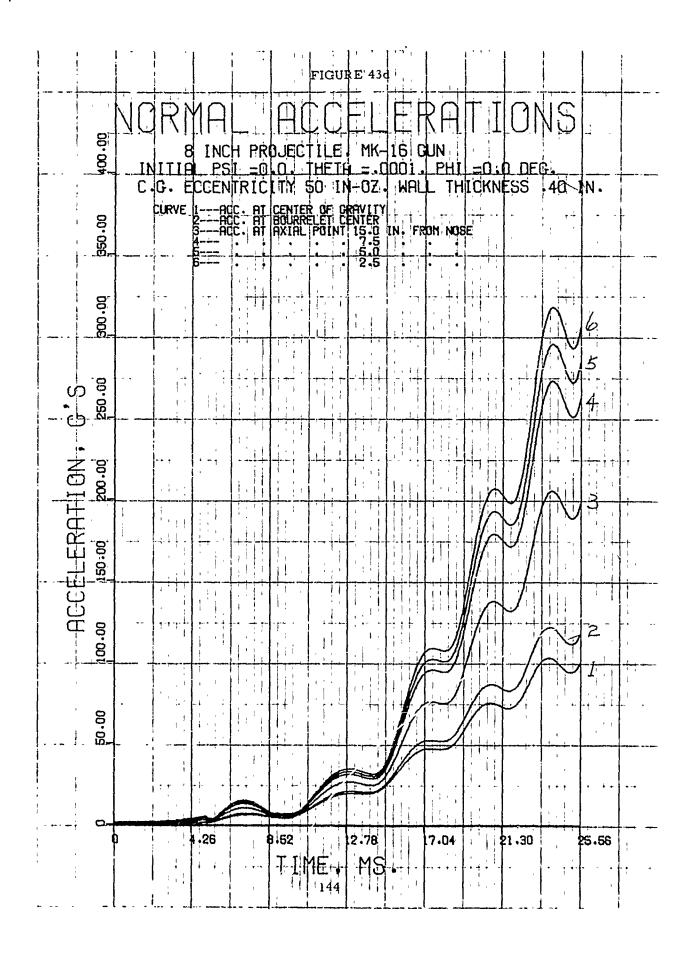


				<u> </u>	,	FIGU	E. 43						!	<u> </u>
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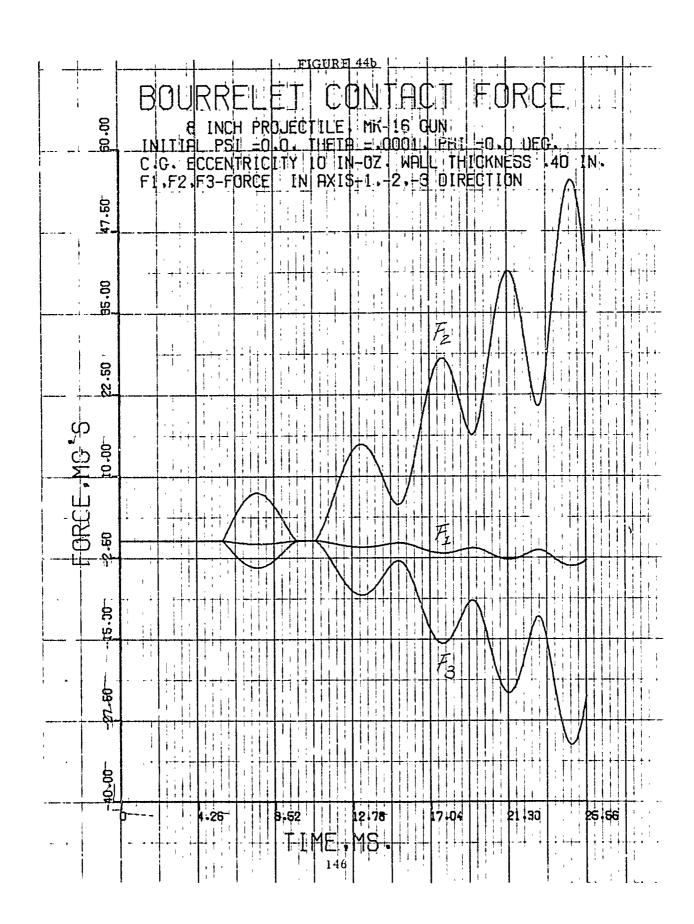
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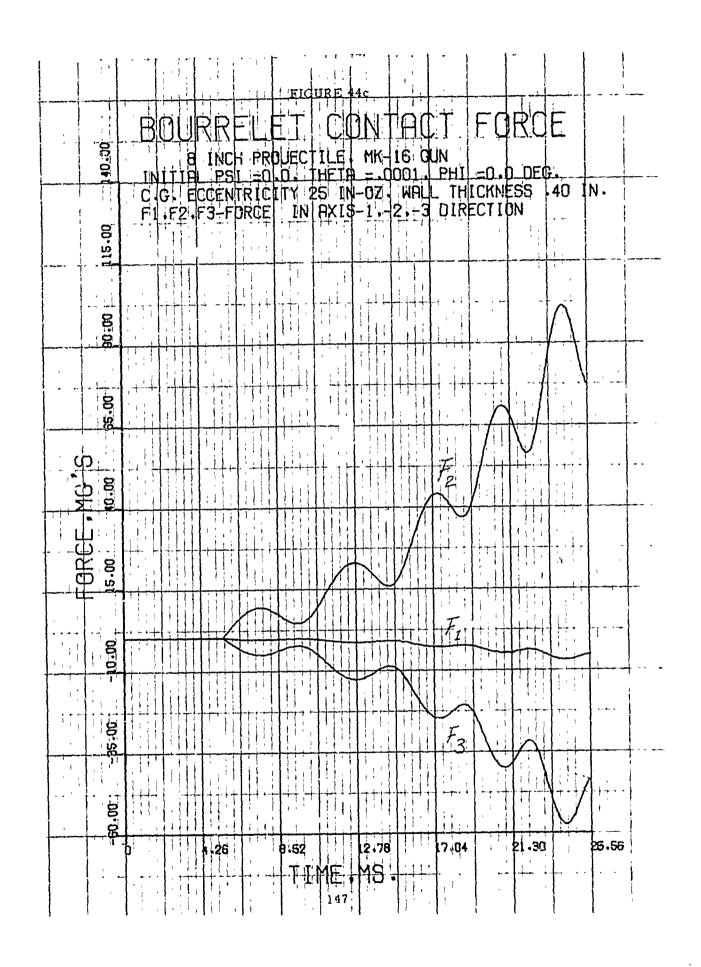


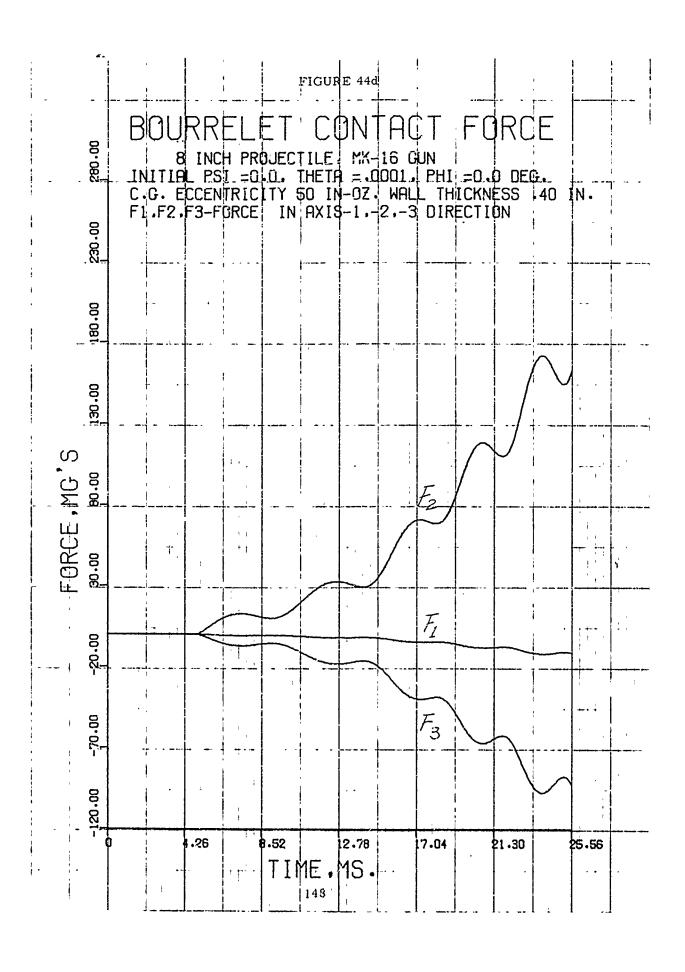


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13. ABSTRACT						
The dynamic behavior of a projectile during acceleration in the gun tube requires						
a quantitative discription, since if balloting becomes excessive, undesirable						
conditions such as damage to fuzing, shell body engraving, inaccuracy of fire due to						
yaw, and yaw velocity at the muzzle may						
utilize the equations of motion derived in a	an earlier rep	ort title	d, "Transverse			
Motion of an Accelerating Shell" [] to des						
XM673 projectile fired in the MK-16, MCI						
Most previous solutions which have appeared in published works to date discuss						

Most previous solutions which have appeared in published works to date discuss the problem in a simple way, or consider separately the main factors that effect projectile motion. Effects of friction forces at the bourrelet and the driving band, changes of the eccentricity and the location of the center of gravity, and the wall thickness of the shell were considered in this formulation.

The analysis shows that the contact of the bourrelet on the gun tube is intermittent when the C. G. eccentricity is zero or very small and the contact is continuous when the eccentricity is large and that this parameter is the one that most effects the performance of the projectile and the assoicated fuze. The analytical results are presented in graphic form.

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